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Virtual Reality Technologies and Systems

Sabrina Sestito

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Air Operations Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

The aim of this report is to provide an overview of recent developments in some key virtual reality (VR) technologies and systems. Various definitions of VR will be provided. Current VR hardware (Head Mounted Displays, BOOM devices, Stereo Glasses, Convolvotron, Gloves, Tracking devices) and VR software (computer graphic issues, object representation and toolkits) will be discussed. Current innovative systems will then be presented which will include a discussion of SmartScene, PolyShop, Responsive Workbench, Virtual Workbench and the CAVE. Finally, a brief discussion of applications and areas of research will be presented.

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Executive Summary

This report describes some of the key areas of Virtual Reality (VR). VR is an encompassment of an environment (visual, audio, haptic), plus the humans within the environment, plus the interfaces between the two. Therefore, a description of VR needs to include many aspects. Initially, various definitions of VR are given. The importance of immersion is highlighted. Following this, a brief description of the human senses is given.

Common VR hardware is then discussed. This includes a discussion of Head Mounted Displays, Boom devices and Stereo glasses. As hands are a natural interface for humans, gloves are discussed in detail next. The Convolvotron, which is used to simulate 3D sound, is also briefly described. An examination of several types of tracking devices is then given; their advantages and disadvantages are highlighted.

Under VR software, many issues are discussed. Basic computer graphics terms are defined. The objects which inhabit the virtual environment are described; the importance of these objects having real world behavioural characteristics is highlighted. Building virtual environments is then discussed. Toolkits provide an easier manner in which to construct virtual worlds. Several examples of toolkits are provided, including a discussion of the WorldToolKit (WTK) which has won awards for excellence.

Once the hardware and software foundations were set, several innovative systems are then described. SmartScene and PolyShop are two systems which use VR technology for the construction of terrain databases. The Responsive Workbench and the Virtual Workbench are two systems centred around a working table. These have been primarily used for medical applications. Finally, the CAVE system is described. This system is based around a room in which a computer generates imagery on three walls and the floor. This system has been primarily used for scientific visualisations. It has great potential for other applications.

The next two sections of this report are basically a list of applications and research being carried out in VR. Under applications, the defence applications, in particular, are listed. Under research, only hardware and software are considered. The final section brings together all the aspects discussed in this report.

The intention of this report is to familiarise the reader with the key areas of Virtual Reality technology and current systems. This will result in better informed decisions about the potential use of this technology being made.

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Contents

List of Abbreviations

2D	Two Dimensional
3D	Three dimensional
AOSC	Air Operations Simulation Centre
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment
CRT	Cathrode Ray Tube
DIS	Distributed Interactive Simulation
DSTO	Defence Science and Technology Organisation
GL	Graphics Library
HMD	Head-Mounted Display
HUD	Head Up Display
LCD	Liquid Crystal Display
I/O	Input Output
SGI	Silicon Graphics Incorporated
VR	Virtual Reality
WTK	World Tool Kit

1. Introduction

The aim of this report is to provide an overview of recent developments in some key virtual reality (VR) technologies and systems. This report will limit its discussion to information on key VR hardware and software components, innovative systems, applications and areas of research. The breakdown of this report is as follows:

- definitions of VR;
- brief description of human senses;
- VR hardware (Head Mounted Displays, BOOM devices, Stereo Glasses, Convolvotron, Gloves, Tracking devices);
- VR software (computer graphic issues, object representation and toolkits);
- innovative systems (SmartScene, PolyShop, Responsive Workbench, Virtual Workbench and CAVE);
- applications (including defence); and
- areas of research (software and hardware).

It is envisaged that the reader of this report will have some understanding of VR and the associated key technologies.

2. Definitions

Fundamentally, Virtual Reality (VR) is concerned with a complete system in which not only is the virtual environment created by a computer (i.e. an image generator), but where the user within the environment is also a prime consideration [Larijani 1994]. The interfaces between the user and the virtual environment are also part of a VR system. Since the user is within the environment, a different perspective of the environment is possible and, as is often the case, a change in perspective yields surprising and new insights [Larijani 1994, McDowall 1994]. This unorthodox perspective is one of VR's strongest strengths.

In this report, a distinction is made between virtual environments and VR. A virtual environment is the world which exists entirely within the memory of the computer [Aukstakalnis and Blatner 1992], while VR contains this virtual environment and the user within it, and all the interfaces needed to connect the two. As discussed later, examples of such interfaces are Head-Mounted Displays (HMDs) and gloves. In the past, the virtual environment term was used in order to disassociate the science of VR from the fantasy associated with VR through various movies and games. In recent times, however, the VR term has once again gained prominence. Figure 1 illustrates a complete VR system by showing the interactions between a Head-Mounted Display, gloves, audio equipment, tracking devices and the computer producing the virtual environment; this figure is an adaptation of the one found in [Vince 1995].

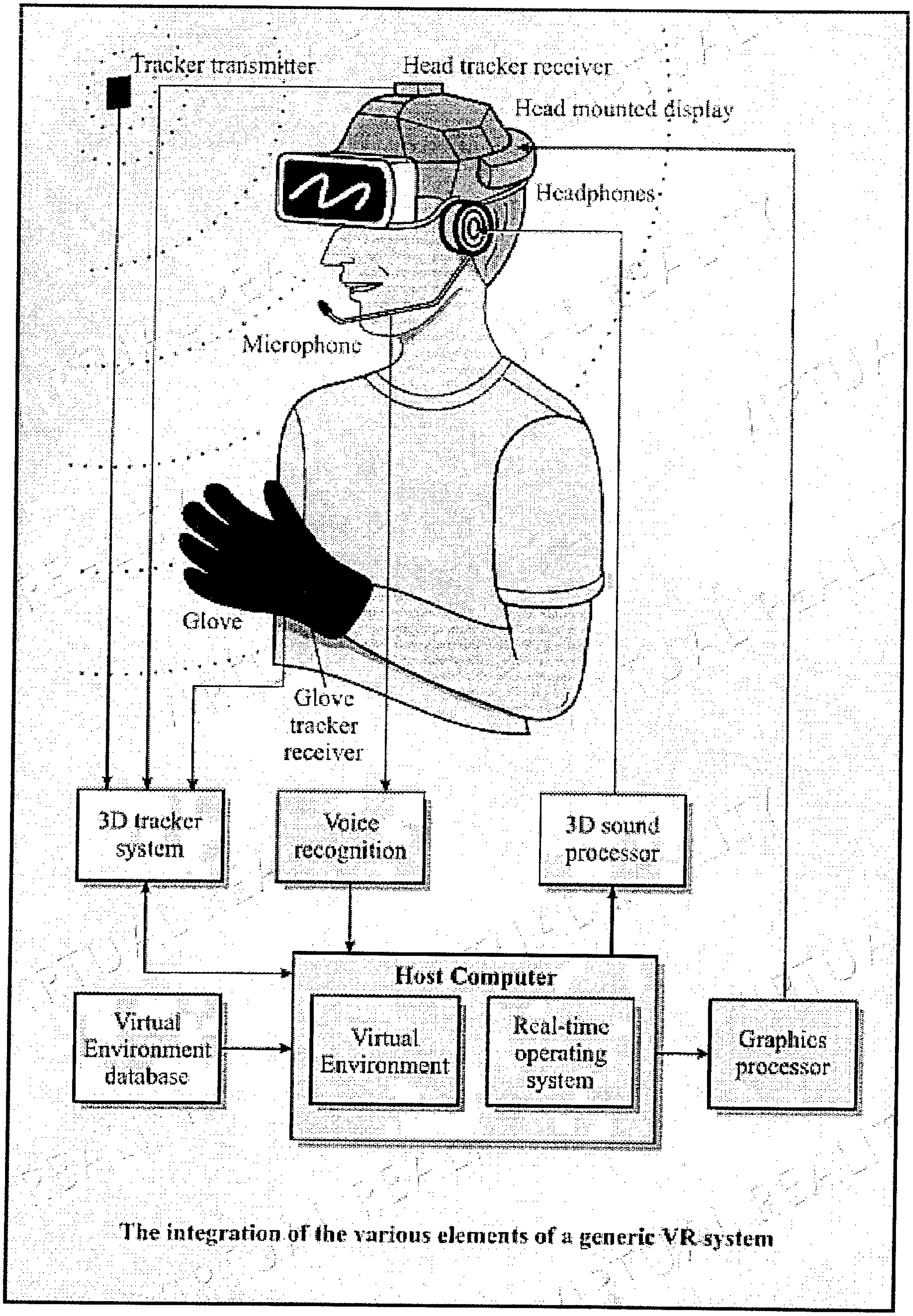


Figure 1: A typical VR system [adapted from Vince 1995].

In the literature there are many diverse definitions of VR [Burdea and Coiffet 1994, Ellis 1994, Kalawsky 1993, Larijani 1994, Lavroff 1992, Pimentel and Teixeira 1993]. According to Burdea and Coiffet [1994], VR is

> *"a simulation in which computer graphics is used to create a realistic looking world. In addition, the synthesised world is not static but responds to user inputs (gestures, verbal commands, etc.)".*

They also state that VR is a high end user interface that involves real time simulation and interactions through multiple sensorial channels (visual, auditory, tactile, smell, taste, etc.). Ellis [1994] states that VR potentially provides a new communication medium for the human-computer interaction. From these definitions, VR encompasses issues such as user interfaces, computer graphics and fidelity, and human sensorial aspects.

Other definitions emphasise the direct simulation of the human senses in order to create the experiences of another world. For instance, Lavroff [1992] defines VR as a system which

> *"envelops you in an artificial world that feels real, that responds to your every move much as the real world does".*

According to Kalawsky [1993], VR is a

> *"synthetic sensory experience that communicates physical and abstract components to a human operator or participant."*

Kalawsky also states that a true VR system is one where the human is immersed in a computer simulation that imparts visual, auditory and force sensations and where the interaction with the components is through responses being sensed appropriately and coupled into the environment.

However, according to Pimentel and Teixeira [1993], VR is

> *"an immersive experience in which participants wear tracked, head-mounted displays, view stereoscopic images, listen to 3D sounds and are free to explore and interact with a 3D world".*

This definition, however, is a little restrictive in that it states that Head-Mounted Displays must be part of a VR system. As illustrated later, the CAVE and the Responsive Workbench are VR systems which do not use these devices. Some people, in fact, have an aversion to wearing large, uncomfortable, heavy devices on their head [Poston and Serra 1994, Bryson and Feiner 1994]. Finally, Larijani [1994] states that by putting the user into an active and participatory role in the world created by the computer, VR is attempting to erase the boundary between the human and the computer.

A flight simulator is commonly associated with simulation and virtual environments. A flight simulator uses a computer to create a perspective view of a 3D virtual world; the orientation of the simulated aircraft determines the view of the world. As stated by Vince [1995], VR extends this in two important areas:

- the degree of user immersion; and
- the degree of interaction the user has with the virtual environment.

One of the crucial aspect of VR is immersion [Aukstakalnis and Blatner 1992, Vince 1995]. According to Burdea and Coiffet [1994], VR is composed of the three I's; interaction, immersion and imagination. Similarly, Lavroff [1992] states that immersion, navigation and manipulation are the major components of VR. The ability to immerse the user in a computer generated experience as an active participant rather than a passive one is essential in a VR system [Vince 1995] Two extremes of immersion are possible. One extreme is a totally immersive VR system based on head-mounted displays or other immersive display technology, while the second extreme is desktop VR emerging from animated Computer Aided Design (CAD) [Kalawsky 1993]. The difference between the two is the degree of immersion. Basically the higher the interactivity, update rate, image complexity, sound quality, and stereoscopic and field-of-view, the higher the feeling of immersion [Pimentel and Teixeira 1993].

Part of the feeling of immersion is the feeling that the world changes as you change. Thus, immersion is enhanced by allowing the user's head movements to control the gaze direction of the synthetic images; this provides the brain with motion parallax information which complements the other visual cues. This requires tracking the user's head in real time; the user's head must be synchronised with the computer generated images [Aukstakalnis and Blatner 1992, Burdea and Coiffet 1994, Vince 1995]. By sensing the position and orientation of the user's head with a tiny sensor and feeding the resulting data into an image generator, a computer synthesised view of a world from the user's point of view can be generated [Kalawsky 1993]. In addition, by tracking the user's hands through the use of gloves or other sensors, immersion and interaction are further enhanced. Glove manipulations (i.e. hand movements) are an intuitive interface for humans [Abel et al 1995]. Another advantage of gloves is that they can provide tactile feedback which allows the user to "touch" or "feel" an object in the virtual environment. The sense of sound also enhances the illusion if, as the user's head moves, the sound of a stationary object remains stationary. Refer once again to Figure 1.

Humans are the users of VR and therefore the immersive feel of a system must satisfy the human's perception of immersion. As such, our five senses, in some fashion, must be stimulated [Kruger et al 1995]. The obvious sense of sight can be readily identified as being the visual representation of the environment. Here, aspects such as realism and fidelity must be considered. This area has received the greatest attention in the simulation community. The sense of hearing can be satisfied by various audio equipment, while for the sense of touch/feeling, this can be satisfied by haptic and force feedback devices. Only recently, the sense of smell is being considered [Lavroff

1992]. The sense of taste has not been addressed. A very brief discussion of the human senses are discussed in the following section.

Issues relating to satisfying the human senses in a virtual environment will be discussed in the section on VR Hardware. For the visual sense, Head-Mounted Displays (HMDs), BOOM devices and Stereo glasses will be discussed. For interaction and the touch/feeling sense, gloves will be discussed. A device for simulating sound in a VR system will then be briefly described. Tracking the user's head and hands is crucial for VR and so, tracking devices will also be discussed.

Software aspects are then discussed. Basic computer graphics aspects as well as object representation and behaviour in a virtual world are presented. Commercial and free toolkits which enable one to create a virtual environment will be presented. Some of the hardware and software sections are an expanded version of [Sestito 1996].

Once this foundation has been set, several innovative systems will be presented and which comprise:
- two systems which use VR for the construction of visual databases;
- two systems which use a workbench as their basic work area; and
- a system which uses a large room as its basis.

Some applications will then be presented. Finally, current areas of research will be discussed.

3. Human Senses

3.1 Sight

Of all the human senses, the sense of sight is the most dramatic. The eyes provides us with the greatest amount of sensory information about our physical surroundings [Aukstakalnis and Blatner 1992]. Depth perception by humans gives them the ability to see scenes in three dimensions (3D) [Larijani 1994, Lavroff 1992].

In order for humans to perceive depth, either one or two cooperating eyes can be used [Burdea and Coiffet 1994]. With one eye, depth is perceived based on cues inherent in the actual images, such as shadows, texture, etc. Motion parallax is also used as closer objects seem to move further than distant ones when the head is moved.

With two eyes, stereopsis is the basis of depth perception. When looking at an object, each of the eyes receives a slightly different image of the object. The brain uses the horizontal shift in the image positions registered by the two eyes to measure depth [Burdea and Coiffet 1994, Lavroff 1992]. The greater the convergence, the closer the object. Kalawsky [1993] provides the following definition of Stereopsis:

> *"The horizontal separation of the eyes causes objects at different depths to fall on non-corresponding parts of each retina with the magnitude of separation a function of the difference in depth of the objects. When 2D scenes containing*

disparity are presented to the eyes, they fuse to form a striking impression of depth or volume. Stereopsis does not provide a cue to absolute distance unless other cues are present".

The total viewing angle of a human is called the field of view. This is approximately 180 degrees horizontally and 150 degrees vertically [Burdea and Coiffet 1994]. Depth perception, combined with a wide field-of-view and stereo imaging enhances the immersive feel within a VR system.

3.2 Touch

The sense of touch or feeling is important because it confirms what our eyes see. In fact, our sense of touch is more reliable than vision. Humans have two systems which provides us with haptic information [Aukstakalnis and Blatner 1992];

- mechanoreceptors - extremely sensitive mechanisms which measure the pressure or deformation of the skin; and
- proprioception - the complex sets of muscles within our hands, which provide feedback from muscles and tendons.

Together, mechanoreceptors and proprioception make up the haptic systems, providing haptic cues which convey information about our environment [Aukstakalnis and Blatner 1992].

Mechanoreceptors cues give information about shape, texture, temperature and tactile acuity (measure of tactile precision - noting how close together 2 separate points of tactile simulation can be before they feel like only one point). Hundreds of thousands of these are required. Proprioception feedback gives information about shape, force and firmness. Our fingers not only move around an object, but send information about the object to the brain. So, the ability to reach out and touch something is not enough for humans, because in the real world, when you reach out and touch something, it touches you back. Without proprioception, there is no way to detect the boundary on an object in VR [Aukstakalnis and Blatner 1992].

Tactile (sense of touch or pressure applied to skin) and force feedback (forces acting on muscles, tendons and joints) are both part of the haptic perceptions. So, for example, when one picks up a pen, the sense of touch communicates the smoothness and texture of the pen, while force feedback describes the pen's weight and firmness [Pimentel and Teixeira 1993]. Therefore, in order to create the sensation of touch, one needs to have both tactile and force feedback devices; collectively these are known as haptic devices.

3.3 Sound

Humans use the sound generated in their environment for many things. Some examples are given below [Barfield et al 1995]:

- determining the size of a room through the reflection of the sound off the walls and ceiling;
- obtained an indication of the material of a room through the reflection of sound;
- the Doppler effect helping us to estimate the speed or closeness of an approaching vehicle; and
- the sound generated by two objects interacting give us an indication of what the two objects are.

Sound, besides giving humans information about their environment, is used by humans to direct their eyes to the source of the sound. In a sense, sound gives humans a sense of direction [Barfield et al 1995].

The basis of the localization of sound by a human is performed by several cues. Basically,

- the azimuth of the sound is determined by the interaural time difference (i.e. the differential delay between the arrival of a sound at the two ears) and the interaural intensity difference (i.e. the differential of the intensity of a sound at the two ears) and
- the elevation of a sound is determined by spectral cues (which result from the location-dependent filtering properties of the head and pinnae).

The sense of sound complements our visual skills [Barfield et al 1995, Larijani 1994]. Sound is important to a person's spatial awareness and is crucial when visual clues are minimal or absent. The purpose of sound is to enhance the illusion of reality or augment information provided to the user through other channels. For realism, the direction of the sound must remain constant, even though the head is moving in the environment. This type of stereoscopic 'surround-sound' is sometimes called spatial sound.

3.4 Other Senses

The other two senses have not been given much consideration in the VR field. The sense of smell allows humans to detect odour through their noses, while the sense of taste is experienced through the taste buds on their tongues. However, some have started to consider methods for the incorporation of smells into their VR systems [Lavroff 1992, Moshell et al 1995].

4. VR Hardware

Lavroff [1992] states that immersion in VR is primarily a function of hardware. Some systems use a Head Mounted Display (HMD) to simulate the visual and auditory sense and to track the head's movement in 3D. Additional input devices, such as gloves, can sense the hand's positions and orientation. Data about the position and orientation in three dimensions (3D) of the user's head and hands need to be continually fed into the computer so that the visual, auditory and haptic sensations are all synchronised with the head and hands movements. Tracking devices are used for this purpose.

The realism of the situation, in the sense of satisfying the human senses, is critical for the successful 'feeling' of immersion. Barfield et al [1995] state that in order to develop VR hardware and applications, it is important to have a good understanding of the human's sensory system capabilities; the authors provide comparative tables of current (1995) VR hardware and the human sensory capabilities. The importance of the ultimate use of the systems is also emphasised by Barfield et al [1995]. They indicate that the application should be the prime consideration when considering VR equipment. For instance, for a navigation application, a wide field-of-view is required, while for a tele-operated application, only a small field-of-view is required; this consideration will have a large impact upon the choice of hardware.

According to Ellis [1994], the illusion of VR is created through the operation of three types of hardware:

- sensors which detect the operator's body position and movements;
- effectors which stimulate the operator's senses; and
- special-purpose hardware that links sensors and effectors together to produce sensory experiences resembling those in a physical environment.

The next sections describes typical hardware needed to simulate a feeling of immersion. For the visual sense, Head Mounted Displays, Boom devices and Stereo glasses are all described. Gloves are the main equipment used for satisfying the feeling sense and for interacting within the virtual world. The Convolvotron is briefly described as the major equipment for simulating sound in a 3D virtual world. Under the tracking sections, six types of trackers are discussed. Some final comments are then made. Note that a good source of information about the companies which provide VR hardware is the VR Sourcebook [1996].

4.1 Hardware for Visual Immersion

4.1.1 Head Mounted Displays (HMDs)

According to [Larijani 1994], as most of human's sensory channels are located in the head (sight, sound, smell and taste), it follows that some sort of headpiece is an important part for an interaction with the virtual world. A Head Mounted Display (HMD) is an attempt to satisfy these sensory aspects. Basically, the visual component of a HMD is composed of an image source and optics which relay images to display screens.

The optics of the HMD [Pimentel and Teixeira 1993]:

- allow one to focus on a display screen 2 to 3 inches from the face; and
- increase the field-of-view of the displayed image.

These special optics are needed to allow the eyes to focus at such short distances without tiring and are also needed to magnify the screen image to fill as much as possible of the eye's field-of-view. The optics are actually placing the image at a comfortable distance for the eyes. An example of such optics are the LEEP optics [VR Resources 1995] which are extremely wide output lenses used to accommodate all user intrapupillary distances [Burdea and Coiffet 1994]. The images generated by the computer are sent to the pair of miniaturised displays on the HMD. As each eye gets its own slightly different image, the effect is one of viewing a 3D world [Larijani 1994].

The computer generates the images appropriate to the user's attitude and position. The images are synchronised with the user's head movements. The HMD monitors not only the head's orientation, but its absolute location as well [Lavroff 1992]. One method used for tracking is through the use of an ultrasonic transmitter mounted on the HMD and a receiver mounted on or near the computer. By moving around, the computer receives data which it uses to modify the size of the objects in the user's field-of-view. Another approach for tracking uses magnetic sensors and magnetic field surrounding the HMD. As the user moves within the magnetic field, the sensors track the user's position and sends this information to the computer [Lavroff 1992].

There are two types of HMDs. These are distinguished by whether the primary source of the images is either on or off the HMD. The HMDs with the image source on the HMD are cathode-ray-tube devices (CRTs) and liquid-crystal displays devices (LCD). Recent developments have resulted in the CRT devices being the preferred option due to high resolution capability and subsequent bright, high resolution pictures [Burdea and Coiffet 1994]. However, as the resolution gap narrows, LCD may once again be in fashion. LCD are good because they are light and flat, even though early versions were grainy [Larijani 1994]. The disadvantages of these HMDs is that:

- they are usually heavy; and
- the physical danger of having the electronics so close to the human body.

Figures 2 and 3 show various types of CRT and LCD HMDs, respectively; these figures were adapted from Burdea and Coiffet [1994].

The second type of HMD where the primary source of the images is off the HMD are fibre optics devices [Burdea and Coiffet 1994, Larijani 1994, Lavroff 1992]. Here, the image is produced externally and linked to the HMD via fibre optics. The disadvantage of this type is that the HMD has large cables protruding from the HMD. Figure 4 shows one such HMD.

For the military, the technical specification for a HMD is of prime importance, followed by the consideration of cost. Here, one consideration is that a pilot is unable to wear any head piece which could have an averse effect during high g-force manoeuvres. In addition, the pilot requires high-resolution information to be displayed upon an optically accurate and rugged display [Vince 1995]. To this end, the developers of these systems have explored the use of cockpit-mounted displays coupled to the pilot's helmet through flexible coherent fibre optic bundles [Vince 1995]. The computer generated images are then superimposed over the pilot's view of the real world using off-axis optics [Vince 1995]. Other technical specifications include a field-of-view of 60 degrees horizontal and 55 degree vertical, with 45 degree binocular overlap, minimum aberrations, peripheral vision, eye relief and scene collimation [Vince 1995]. As expected, a HMD satisfying all of these requirements would be fairly expensive [Vince 1995].

The Air Operations Simulation Centre (AOSC) has been set up at the Defence Science and Technology Organisation (DSTO) in Melbourne, Australia [Feik and Mason 1993a, Feik and Mason 1993b]. The Centre has purchased a high-end colour SIM-EYE™ HMD which was developed by Kaiser-Optics; see Figure 5. This HMD is a binocular colour display system with miniature cathode ray tubes, collimating optical relays, a head tracker and an audio headset in a lightweight helmet. To allow direct viewing of a simulator cockpit, the relay optics are partially transparent. The field-of-view of this HMD is 60 degrees circular per eye with a resolution of 1024 lines x 1280 pixels per eye. The colour SIM-EYE™ HMD satisfies the technical specifications required for military purposes [Vince 1995]. The HMD will be used to present computer generated imagery to pilots over the full field of regard available in real military aircraft.

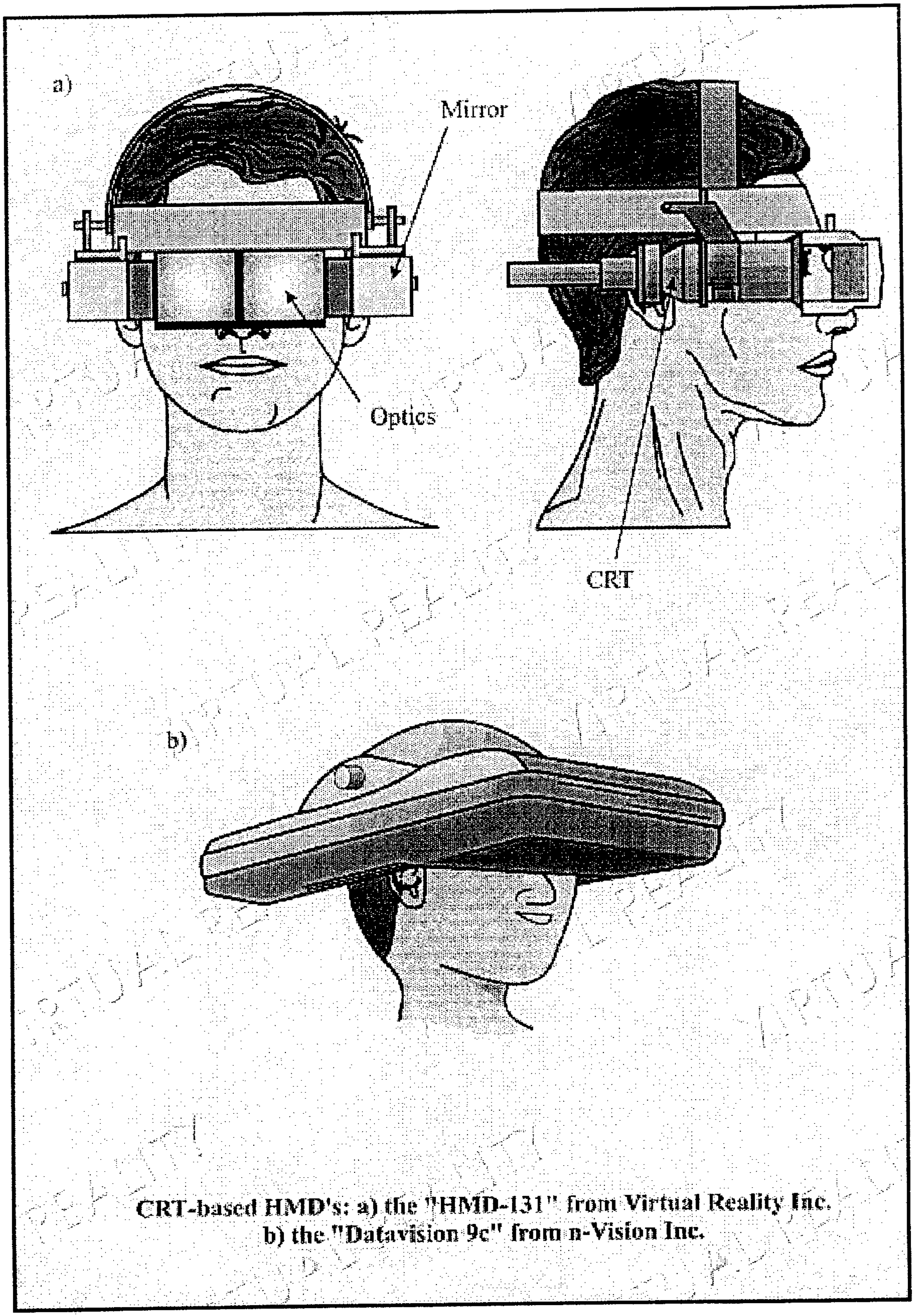


Figure 2: Examples of CRT Head-Mounted Displays [adapted from Burdea and Coiffet 1994].

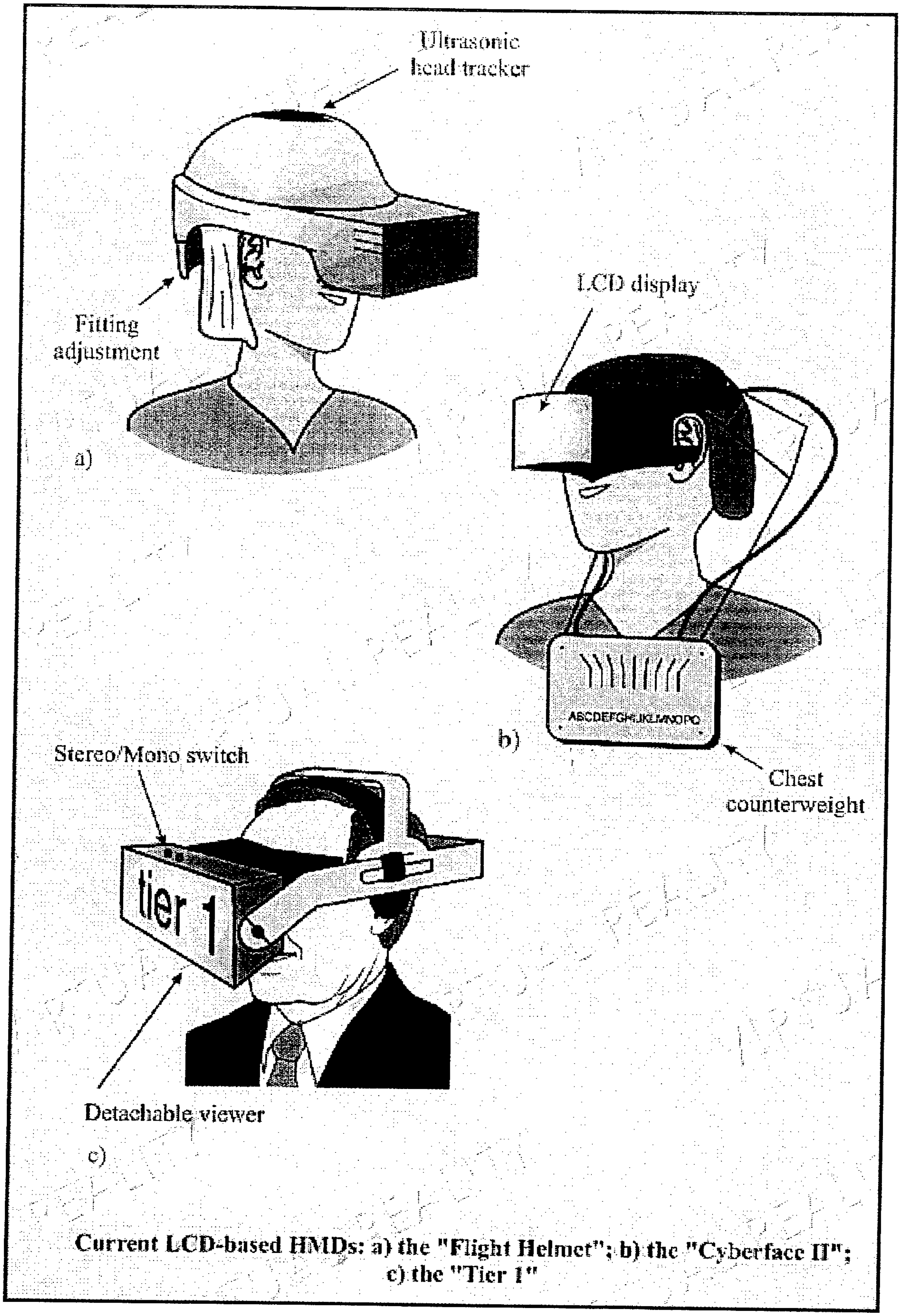
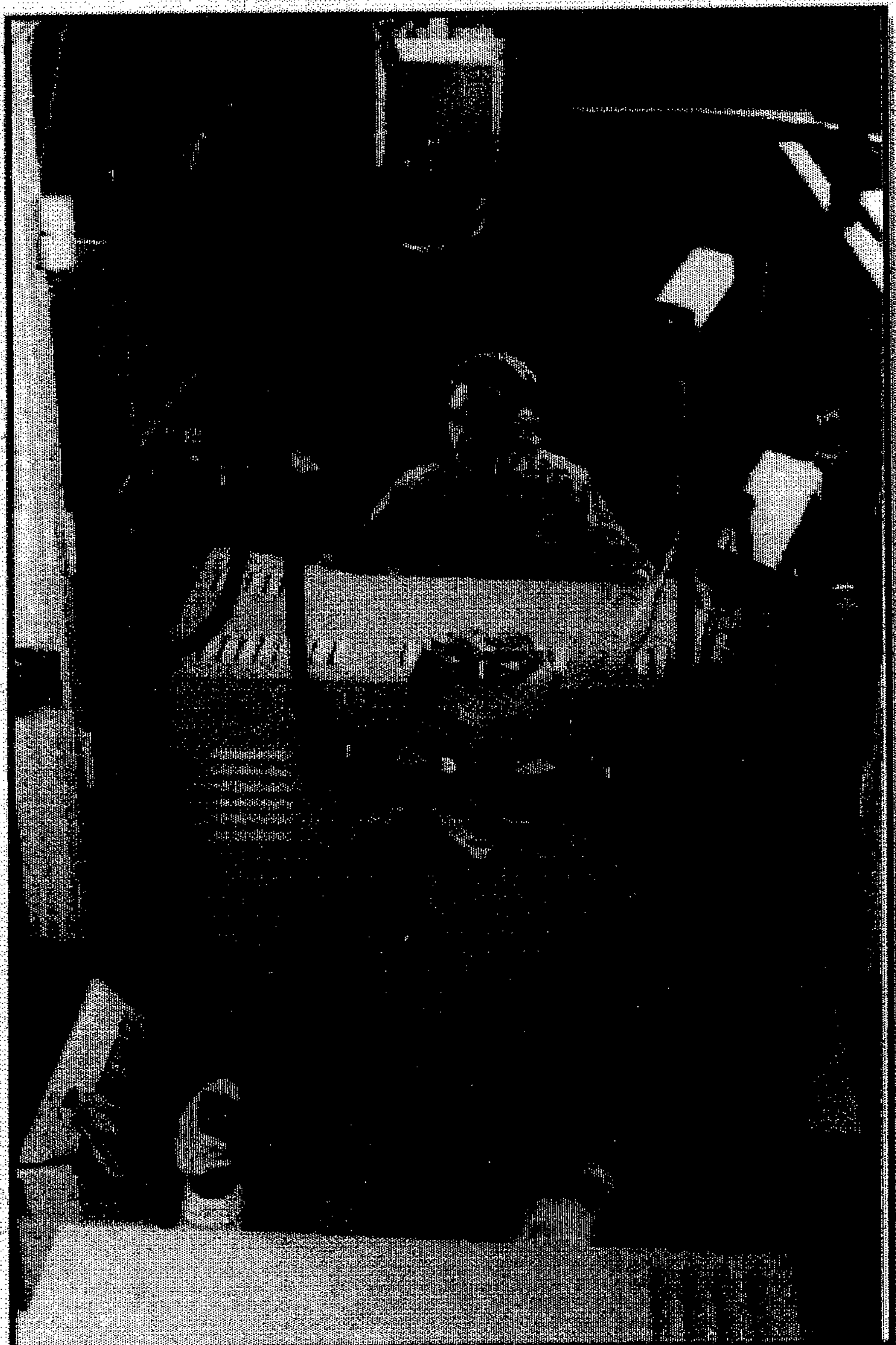


Figure 3: Examples of LCD Head-Mounted Displays [adapted from Burdea and Coiffet 1994].



Fibre Optics Head Mounted Display

Figure 4: A fibre optics Head-Mounted Display (adapted from Aviation Week & Space Technology, Nov. 27th, 1989).

Figure 5: The Air Operation Simulation Centre's Head-Mounted Display (SIM-EYE™ by Kaiser-Optics).

Visual immersion relies on the field-of-view, frame refresh rate and head tracking. Many HMDs provide wide horizontal and vertical fields of view with a consistent image resolution. However, according to [Aukstakalnis and Blatner 1992], by providing a high-resolution inset whenever the user is looking and generating a low-resolution background image everywhere else, the computational load of the system would be reduced. The field-of-view for high-performance HMDs does not exceed 70 degrees per eye [Larijani 1994]. The ultimate goal of these HMD systems is to improve optical systems so that a user sees a 180-degree field-of-view displayed at any one time. Also, efforts are being made towards improving the control of the generation of the images to both left and right displays [Larijani 1994].

For prices and a comparison of current HMDs, a good source of information is Ian's VR buying guide [Buying Guide 1996]. This guide provides a comparative table which contains resolution, field-of-view, type of display and price of several HMDs. As can be seen from this list, HMDs vary in price from (where h = degrees horizontal and v = degrees vertical):

- $800 (46h and 35v, with 428x224 resolution) to $8,700 for colour LCD HMDs;
- $19,900 to $135,000 for colour CRT HMDs; and
- $250,000 for CAE's fibre optics HMD (127h and 66v, with 1000x1000 resolution).

The current SIM-EYE ™ HMD with a resolution of 1024 x 1280 lines and a field-of-view of 100 degrees horizontal and 50 degrees vertical, cost $135,000 [Buying Guide 1996].

4.1.2 Boom Devices

An interesting variation of the HMD is the BOOM device. BOOM is an acronym for Binocular Omni Orientation Monitor [Larijani 1994] and was developed by Fakespace Inc. The BOOM is a floor-standing device consisting of two rings mounted in such a way (at right angles to each other) that a monitor used to view virtual environments remains suspended in a horizontal plane between them regardless of its platform motion [Larijani 1994]. A BOOM is priced at $74,000 [Buying Guide 1996].

BOOM uses a counter-weighted boom design to eliminate the problems with optic weight and display size. That is, it uses an articulated, counterbalanced support structure and as such, allows much higher resolution CRT devices to be used instead of the low resolution LCD displays [Pimentel and Teixeira 1993]. This display supports up to 1,280x1024 pixels/eye resolution [VR Resources 1995]. The BOOM can be easily pulled to the user's face when the user wants to step into the virtual world [Nomura 1994]. It can also be operated with the hands or hands free. BOOM devices ranges from monochrome (BOOM) to full colour (BOOM3C). The six joints in the supporting counter-balanced arm enable the user to move the BOOM within a sphere of approximately two metre radius [Vince 1995].

Six shaft encoders measure the position and orientation of the display device, providing a complete six degree of freedom sensing (i.e. x, y, z, roll, pitch and yaw). These encoders also eliminate most of the delay between physically changing one's view and seeing it change in the display. Smaller versions that can attach to an engineer's desk are also possible [Pimentel and Teixeira 1993].

4.1.3 Stereo Glasses

Liquid crystal shutter glasses are a cheaper alternative to HMDs and BOOM devices. These glasses are placed over the eyes. When wearing such glasses, the user perceives objects in 3D. The cost of such glasses is $985 [Buying Guide 1996].

These liquid crystal glasses are manufactured by the StereoGraphics Corporation. They work in the following manner. Each eye is shut down alternately 30 times a second. By synchronising the glasses with a TV screen by way of an infrared signal box, the glasses are alternately charged to create an imperceptible shading over one eye at a time. This shutter effect physically manipulates the eyes into seeing 3D. Also, these glasses sometimes have an in-built, six degree-of-freedom head tracker system [VR Resources 1995].

4.2 Gloves

The use of gloves adds a sense of realism to VR systems. In addition, the area of interaction or freedom of motion of a hand (i.e. glove) is a lot larger than, say, a mouse. A mouse is limited to 2D, while a glove (i.e. hand) is not; see Figure 6. Additional degrees of freedom can also be obtained by sensing individual finger movements

[Burdea and Coiffet 1994]. The other use of gloves is for the feeling of touch. This will be discussed later.

Gloves use electronics to sense the position and orientation of the hand wearing it. As the hand moves around in 3D space, the gloves sends data to a computer in the form of 3D coordinates [Aukstakalnis and Blatner 1992, Lavroff 1992]. The glove uses a tracking mechanism that can use magnetic detection to determine [Larijani 1994]:

- the spatial co-ordinates of the hand's position;
- where the hand is, in relation to the whole scene; and
- the hand's orientation (i.e. where it is in relation to the imaginary body).

Gloves are usually one way transmitters in that they only transmit the data from the user to the computer. However, some are also able to transmit data from computer to user. These latter gloves increase the realism of the virtual environment, as well as providing a mechanism for simulating the sense of touch [Larijani 1994]. Individual fingers can also be tracked [Burdea and Coiffet 1994]. The computer uses the tracked data to manipulate an object in the virtual world. Movement in the virtual world is synchronised with the hand movements. Some examples of well-known gloves are: VPL DataGlove (first on the market), CyberGlove (replacement for the DataGlove), PowerGlove (arcade games) and Dexterous HandMaster [Burdea and Coiffet 1994].

To sense flexing and movement, various technologies have been used with gloves. Most gloves use fibre optics [Isdale 1993, Larijani 1994, Lavroff 1992, Vince 1995]. This type of glove incorporates a network of flexible optical fibres attached to back of the glove's fingers [Vince 1995]. In order for the computer to determine which joints are flexed and to what extent, the following technique is used. A light of known intensity is shone into one end of the network of fibres and then measured as it comes out of the other end [Vince 1995]. Some fibres are etched at finger and knuckle joints which results in a loss of light when the fingers are bent. Light emerging from the end of the etched fibres is compared against the light emerging from unetched fibres. The computer uses these data to adjust the display accordingly. This is how the DataGlove works [Lavroff 1992, Vince 1995]. Another technique used by EXO's Dexterous HandMaster involves an intricate exoskeleton of magnets and sensors that measure the bending angle of each joint in hand. Several sets of magnets and sensors are connected with a velcro band [Lavroff 1992].

The ability to control finger movements changes from person to person and so any glove should be calibrated for each individual to ensure accuracy [Larijani 1994, Vince 1995]. The choice between the DataGlove and the HandMaster is dependant upon the application. The DataGlove emphasises comfort and style, while the HandMaster emphasises exacting position with a small tradeoff in convenience (i.e. has protruding sensors). Figure 7 and 8 show the DataGlove and HandMaster, respectively; these figures are adapted from [Pimentel and Teixeira 1994]. In 1992, the cost of the DataGlove was $8,000US, while for the HandMaster, the cost was $15,000US [Lavroff 1992]. The CyberGlove, which has now replaced the DataGlove, costs $9,800 (18 sensors) or $14,500 (20 sensors) [Buying Guide 1996].

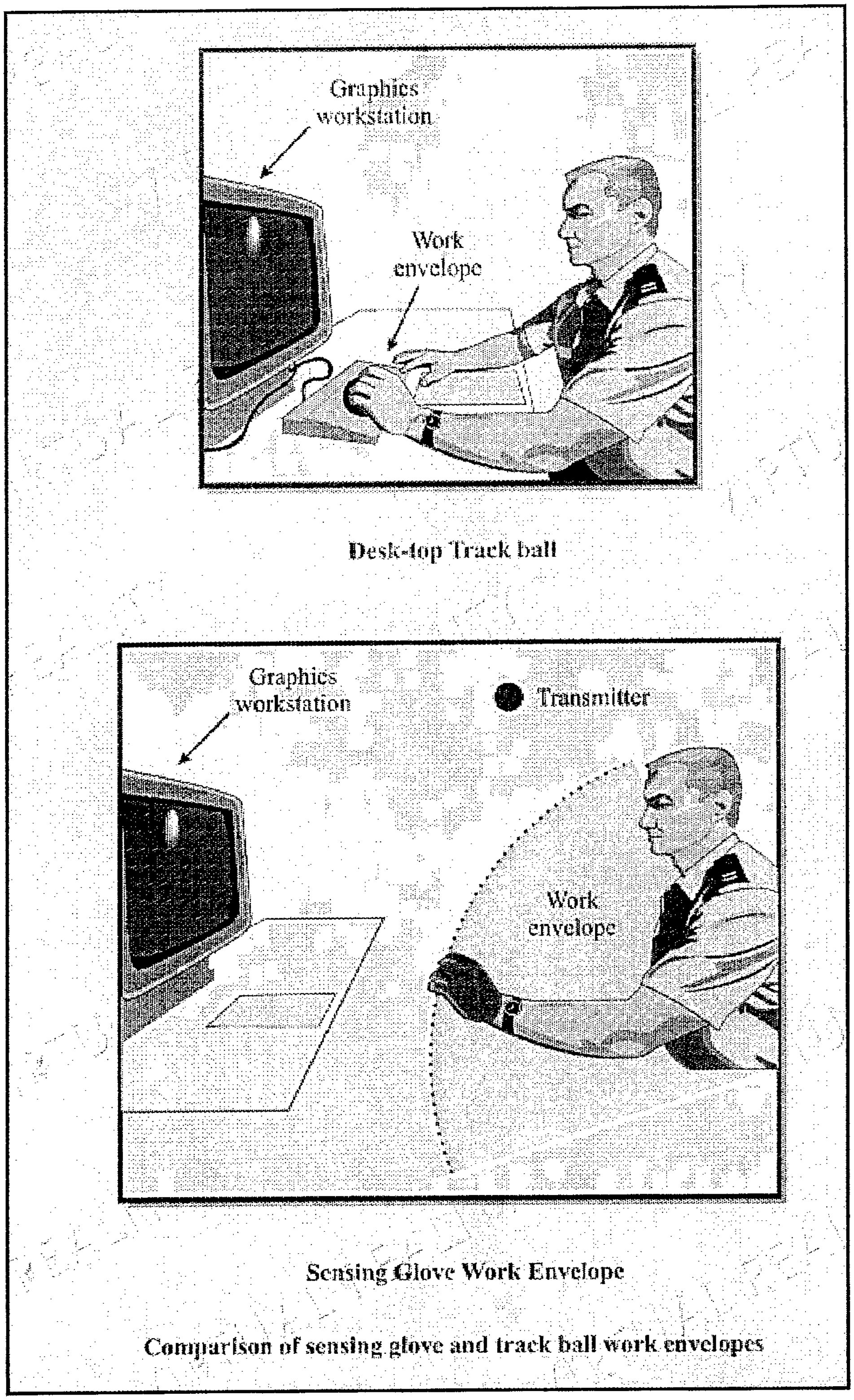


Figure 6: The work envelope of a 2D and 3D instrument
[adapted from Burdea and Coiffet 1994].

Besides being able to sense the position and orientation of the hand wearing the glove, gloves can also be used to simulate touch or feeling sensations. The key to virtual touch is some sort of material pressure or deformation of the skin. Many types push against the hands or arms in order to register a mechanoreceptor or proprioceptive cue [Aukstakalnis and Blatner 1992].

Touch and force feedback, which are collectively known as tactile feedback, is limited to the user's hand and wrist. Touch sensors within the glove provide information on the contact (i.e. surface geometry, smoothness of surface, temperature and texture). For the texture, for example, surface smoothness can be simulated by a series of 3D patches where height (the z-dimension) characterises the surface roughness [Burdea and Coiffet 1994]. Force feedback gives information on total contact force such as weight [Burdea and Coiffet 1994]. The factors recognised as contributing to tactile sensation, according to [Larijani 1994], are :

- a feeling of pressure;
- a sensation of texture; and
- an absence or presence of heat or cold.

For realism, both touch and force feedback are required. In the future, temperature and spillage will also need to be incorporated [Burdea and Coiffet 1994].

Haptic feedback devices range from [Buying Guide 1996]:

- $9500 for a tactile on skin only from Xtensory;
- $14,500 for tactile on hand (i.e. fingertips and palm) from CyberTouch; and
- $100,000 for force feedback on fingers and wrist.

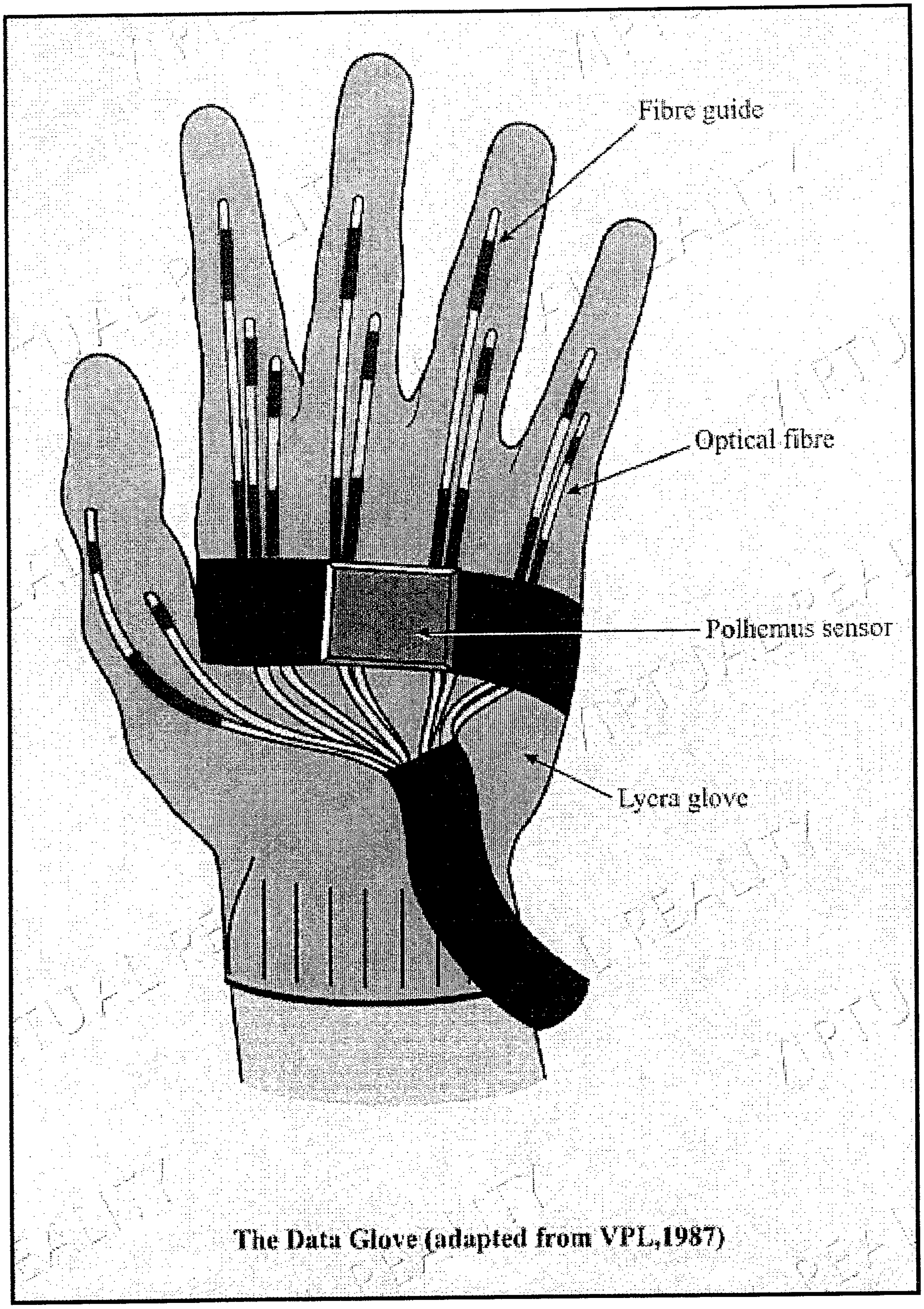


Figure 7: The Data Glove [adapted from Pimentel and Teixeira 1994].

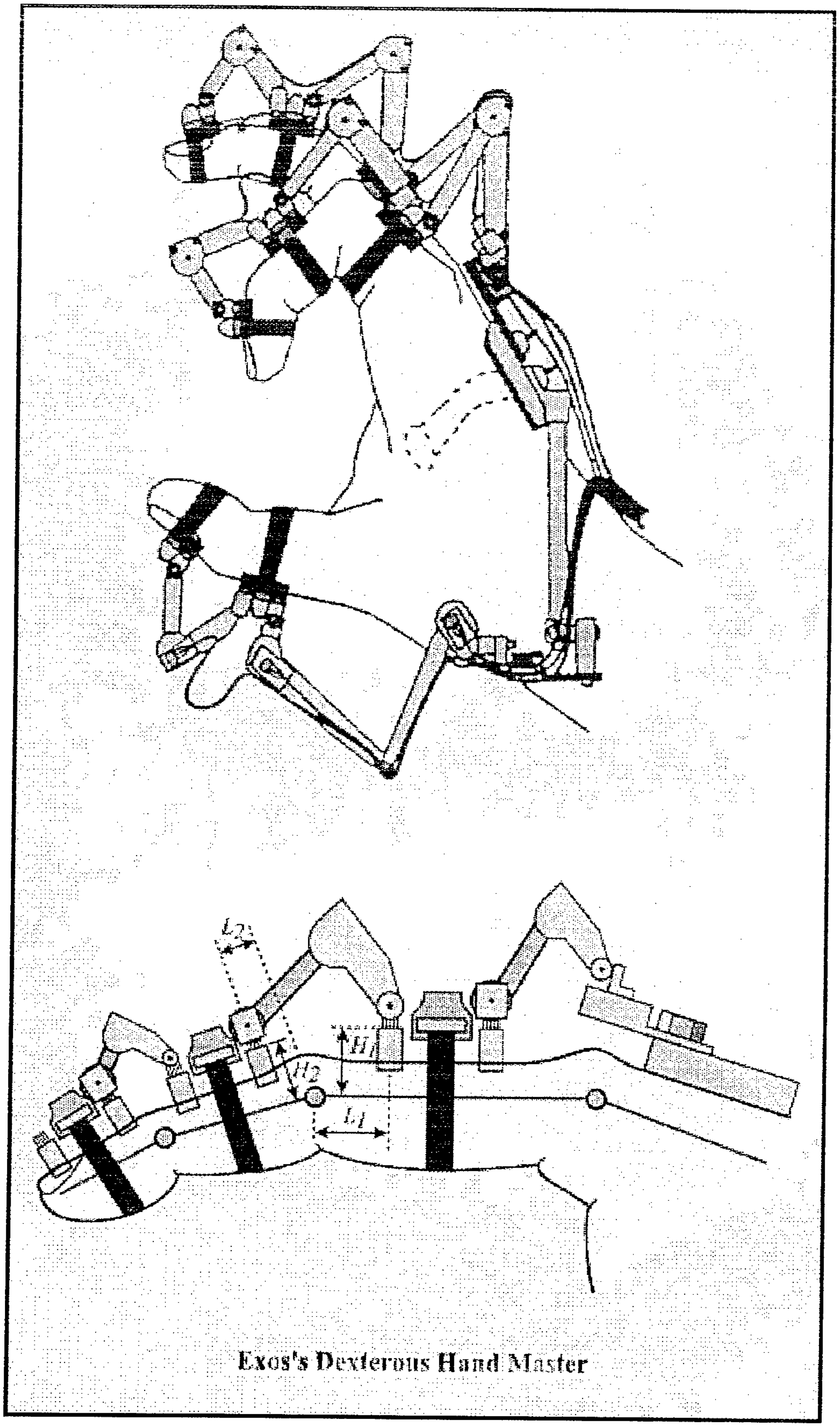


Figure 8: The Hand Master Glove [adapted from Pimentel and Teixeira 1994].

4.3 Three-dimensional (3D) Sound Generators

By using the same software tools musicians use to create computer generated sounds, a VR modeller has unlimited flexibility. The most common way of controlling and generating sounds uses the Musical Instrument Digital Interface (MIDI) standard [Moshell and Dunn-Roberts 1994, Pimentel and Teixeira 1993]. With the computational power of modern Digital Signal Processing devices, many transformations can be applied to sound [Moshell and Dunn-Roberts 1994].

The Convolvotron is a very high speed digital signal processing system capable of producing real-time externalised 3D sound cues [Burdea and Coiffet 1994]. Using a mathematical model of sound reflections and digital sound processing technology, the Convolvotron is able to map one or more sound sources to particular locations in space [Sound Spatialization 1994]. It is capable of presenting four channels of real-time 3D sound over headphones. Thus, the Convolvotron produces filtered sound that appears to come from different locations in space relative to the listener. The Convolvotron costs about $15,000 [Buying Guide 1996].

Basically, the location data from a tracking device is used by the Convolvotron to display sound at a particular location. The Convolvotron firstly digitises the analog sound stream, transforms it to create the illusion that it originated at a particular location, and then converts the digital sound stream back to analog. This analog data can then be played in the stereo headphones of, say, a HMD [Sound Spatialization 1994]. The Convolvotron operates at a peak speed of 320 million operations per second in order to maintain a real-time response.

4.4 Tracking Devices

There are three ways of seeing or interacting with a virtual world - seeing, hearing and feeling. (As mentioned before, little has been done on satisfying the sense of smell or taste.) All of these three mechanisms rely on knowing the actual position of the source. In addition, being able to track the user's head and hands in the virtual world in real time is also important. This is because the user's head and hands must be synchronised with the computer generated images [Vince 1995]. So, by sensing the position and orientation of the user's head and hands with a tiny sensor and feeding the resulting data into a computer graphics system, a computer synthesised view of a world from the user's point of view can be generated [Kalawsky 1993].

Position/orientation tracking requires a data set of six numbers that need to be measured sufficiently fast as an object moves at high speed. These measurements need to be non-contact [Burdea and Coiffet 1994]. These six numbers consist of [Aukstakalnis and Blatner 1992, Burdea and Coiffet 1994]:

- three movement/translation functions, i.e. forward/backward, left/right and up/down (i.e. x, y, z); and
- three turning or rotational functions (i.e. one's head or hands can roll, pitch or yaw).

These numbers relate to the six degrees of freedom that the user has in the virtual environment [Aukstakalnis and Blatner 1992]. Figure 9 illustrates these six dimensions.

Trackers are a physical device which are attached to the object or user so that head or hands movements can be detected. The tracking needs to be done in real-time. For a smooth simulation one needs at least 24 (i.e. movie) or better 30 frames per seconds [Burdea and Coiffet 1994]. Vince [1995] recommends an update rate of 50 updates per second. The Air Operations Simulation Centre runs its simulations at 60 updates per second [Feik and Mason 1993a, Feik and Mason 1993b].

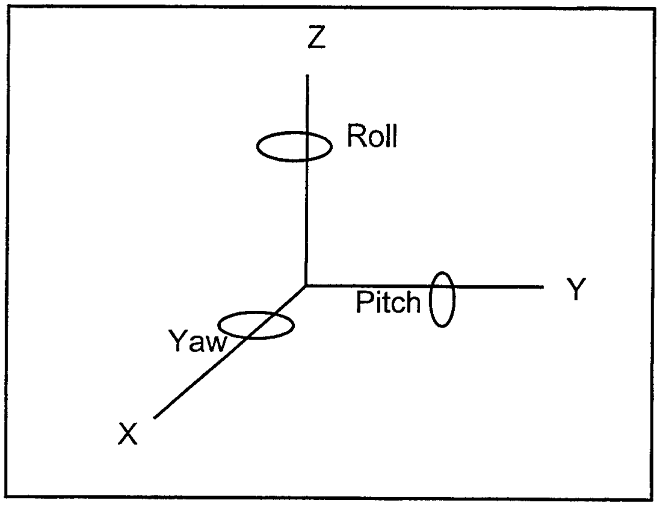


Figure 9: An illustration of the six degrees-of-freedom.

4.4.1 Methods used for tracking

There are six basic position-sensing methods in use : magnetic, ultrasonic, mechanical, optical, inertial and image extraction [Aukstakalnis and Blatner 1992]. A summary of the resolution, accuracy and latency of the magnetic, ultrasonic and mechanical are listed in Table 1 (where figures are taken from [Moshell and Dunn-Roberts 1994]). The six types of trackers are described below.

Table 1: A summary of the characteristics of the magnetic, ultrasonic and mechanical tracking mechanisms [adapted from Moshell and Dunn-Roberts 1994].

	Resolution	**Accuracy**	**Latency**
magnetic	1mm + 0.03	3mm + 0.1	50 msec
ultrasonic	10mm + 0.5	limited by variation in speed of sound due to air density	30 msec
mechanical	1 degree at each joint	4mm	< 1 msec

Magnetic Trackers: The magnetic (i.e. electromagnetic) trackers are the most popular because of the sensor's small size and freedom of movement. These trackers use a low frequency signal generated by a control box, plus six wire-coil sets (three for transmitting and three for receiving) [Pimentel and Teixeira 1993]. The resulting electrical current and magnetic fields can then be used to determine position and orientation. Thus, it uses magnetic fields emitted by a small antenna on the control box and detected by one or more receiving antennas. Most magnetic trackers use alternating current (AC) magnetic fields for measurements (e.g. Polhemus systems); another approach uses direct current (DC) (e.g. Ascension systems) [Aukstakalnis and Blatner 1992]. Several objects can be tracked using the same control box [Pimentel and Teixeira 1993]. This tracker does not rely on line-of-sight to be able to track. However, it has a problem with its sensitivity to large metal objects or other magnetic fields [Pimentel and Teixeira 1993, Moshell and Dunn-Roberts 1994].

Ultrasonic Trackers: The ultrasonic tracker uses an ultrasonic transducer which emits a high frequency sound pulse. This pulse is picked up by three microphones attached to the ceiling. The time delay (i.e. distance) can thus be measured. However, this type of trackers must remain in the line-of-sight of the microphones [Aukstakalnis and Blatner 1992, Moshell and Dunn-Roberts 1994]. Also, this tracker is susceptible to external noise [Pimentel and Teixeira 1993].

Mechanical Trackers: A direct mechanical connection between a reference point and the object to be tracked is the basis of these trackers. It uses a rigid framework both to support the viewing device and to measure position and orientation [Moshell and Dunn-Roberts 1994]. This tracker suffers from a limited range of motion [Aukstakalnis and Blatner 1992, Pimentel and Teixeira 1993].

Inertial Trackers: Another mechanical approach is used by the inertial trackers which use miniature gyroscopes to measure yaw, pitch and roll. These are thus, not true six degree-of-freedom trackers because they can only measure orientation and not translation. However, they can be effective where position information is rarely required [Pimentel and Teixeira 1993]. This type of tracker needs to be further researched in order to be used for the outside [Moshell and Dunn-Roberts 1994].

Optical Trackers: The optical trackers are infrared trackers which determine the position of targets via triangulation technology from cameras at known locations. The orientation is determined by observing multiple targets. These trackers use expensive signal-processing hardware. Optical tracking has been primarily used in cockpit simulators where the range of head motion is fairly limited, but fast update rates are important [Pimentel and Teixeira 1993]. These trackers are fairly accurate [Aukstakalnis and Blatner 1992]. However, fine measurements are difficult, without a large separation between the targets [Moshell and Dunn-Roberts 1994]. Also, these trackers have only a small working volume of approximately one metre cubed. As well, these trackers are susceptible to line-of-sight occulsion [Moshell and Dunn-Roberts 1994, Pimentel and Teixeira 1993].

Image Extraction Trackers: The most calculation intensive tracker is the image extraction tracker. It is the easiest to use from a user's viewpoint, but the hardest from the developers. A video camera or a set of cameras pointed at the participant captures video images describing where the person is and what the person is doing. Visual processing, which is extremely difficult, is then used. It has great potential due to its relative simplicity [Aukstakalnis and Blatner 1992].

4.4.2 General considerations

In general, many tracking devices require clear line-of-sight at all times between sensor and user [Larijani 1994]. General trackers work reliably up to 2 to 3 metres in perfect environment, but in practise this is reduced by local electromagnetic noise. According to Vince [1995]:

- translational accuracy is in order of 2.5 mm;
- translational resolution is in order of 0.8mm;
- angular ranges cover 180 degrees for yaw and roll, with an accuracy of 0.5 degrees; and
- angular ranges cover 90 deg for pitch, with an accuracy of 0.5 degrees.

Data from the tracker are continuously sent in a streaming mode. This is most appropriate and necessary for fast moving objects or when application requires a quick response to a change in the moving object's position. This requires a lot of communication and can be a problem. Burdea and Coiffet [1994] suggest an alternative method of using polling; here, data are only send whenever the host requires it.

The speed in which the virtual scene changes depends on the speed with which the sensor measures motion. This is dependant upon two parameters [Burdea and Coiffet 1994]:

- sensor update rate (measurements per second); and
- the sensor's latency (time delay between action and result).

This speed defines the interactivity between the user and the computer generating the simulated virtual world. This simulation latency is very important. Minimal latency is obviously required. Related to this is also the accuracy of the sensor. The more accurate the sensor for determining the difference between actual and measured positions, the better the simulation follows the user's real actions.

Latency can be defined as the time delay between when a sample is taken and when the data is available for processing. The total latency of a sensor is the sum of the effects of sensor latency, transmission delays (to and from the VR engine), plus the time it takes to re-compute and display a new frame [Burdea and Coiffet 1994]. If latency is > 100 msec, simulation quality degrades significantly and may result in user dizziness and sickness. Low latency and fast refresh rates require a VR engine that has fast CPUs (for modelling of world dynamics and for tool input/output) as well as

powerful graphics accelerators (for drawing fast images). Frame refresh rate is inversely proportional to scene complexity.

Two well-known trackers have the following update rates:

- Polhemus FasTrak updates at 120 Hz; and
- Ascension Flock of Birds at 144 Hz.

Both Polhemus and Ascension claim a latency of less than 10ms. Thus, for a 30 Hz visual update rate, this is acceptable if data can be processing and delivered to the computer generating the image (IG) is less than 10ms, gives a total of 20ms latency [Vince 1995]. The FasTrak costs $6000, while the Flock of Birds costs about $2700 [Buying Guide 1996].

4.5 Final Comments

According to Barfield et al [1995], current VR hardware is only stimulating the visual and auditory senses. Pimentel and Teixeira [1993] also indicate that the object's physical properties (e.g. weight, composition and contact with other sources) need to be implemented in a VR system. In order to have realism, therefore, the sense of feeling needs to be stimulated. Thus, both tactile and force feedback are crucial. Others have also emphasised this point as researchers are attempting to develop better haptic interfaces [Boman 1995]. In fact, according to Moshell and Dunn-Roberts [1994], the biggest limiting factor in training is the requirement for better force feedback based on real-time physical models.

5. Software Considerations

According to Zyda et al [1993], there are three phases involved in the construction of a virtual world:

- hardware phase - items such 3D input devices (i.e. gloves, trackers, etc) and 3D output devices (i.e. HMDs) are considered;
- software phase - the development of software to support the large scale, networked and multi-party virtual environment; and
- final integration phase where the software developed in phase two is used for the construction of a fully detailed, fully interactive and seamless virtual environment.

Phase 1 has had the greatest attention with the development of various HMDs, gloves, trackers and etc. Phase 2 is the hardest in that it provides the foundation of the virtual world. Further developments or refinements to the software are required for phase 3, where the aim is to have things done with minimal delay or hesitation [Zyda et al 1993].

The software of the virtual environment, according to Ellis [1994] must address three separate functions:

- shape and kinematics of entities (i.e. objects and actors) within world;
- their interactions among themselves and with the environment according to real world rules; and
- extent and character of the enveloping environment.

This section attempts to highlights the various software aspects which need to be considered when developing a VR system. As stated above, Zyda et al [1993] and Ellis [1994] have highlighted many important issues. Further ones are discussed below. Once this foundation has been set, the toolkits which are available for creating VR systems will be discussed

5.1 Basic Aspects

This section will attempt to describe some of the basic computer graphics aspects needed when creating a virtual environment. Firstly, the viewpoint of an observer in the virtual worlds needs to be determined. This is crucial as it determines the orientation of objects in the world.

Besides the viewpoint, the actual geometry of an object must also be considered. Any 3D structure, whether a house or a landscape, can be described as a series of 3D coordinates values. Any point in space can be defined by any three points (i.e. x, y and z). Simple rules of perspective guide the computer in creating the 2D image on a view screen using 3D information defining the size and placement of the object. This is a method of generating 3D graphics.

The rendering or drawing of these images is also crucial. This involves examining the 3D model or geometry information and determining how to draw the 3D models on the 2D screen of a display device. Thus, this is the process of calculating the image details and drawing them on a screen. The difficult part is doing the rendering quickly enough for VR systems which require real-time interaction [Pimentel and Teixeira 1993].

Each object in the virtual environment is made up of one or more polygons. A polygon is a 2D segment inside a 3D world that helps make up a 3D object [Aukstakalnis and Blatner 1992]. For example, a cube has six faces; each face could be represent by a separate polygon. The polygon are fitted together to approximate the objects in the virtual world. For instance, to construct a hill, several polygons could be fitted together to approximate the shape of the hill. A larger number of smaller polygons would provide a more natural looking hill. However, using these smaller polygons would mean that the world would take longer to construct. On the other hand, too few polygons would make the hill appear unrealistic. Therefore, the number of polygons used is a tradeoff between realism and speed. In addition, to make a hill seem more natural, each polygon can be coloured a different shade based on how the light strikes

its surface. Here, the position and source of the light source needs to be taken into consideration.

5.2 Objects in the Virtual Environments

There are two parts of an object inhabiting a virtual world. The shape of the virtual objects needs to be considered (i.e. number of polygons, triangles, vertices, etc) as well as their appearance (i.e. texture, surface, reflection, coefficients, colour, etc) [Asch 1992].

The object shape can be created from scratch; this can be tedious [Burdea and Coiffet 1994]. The level of detail of the object shape is determined by the number of polygons used to construct the object. Basically, there are two sets of data needed to define an object; one containing the vertex locations of the object and the other containing the vertex connectivity. These numbers can then be used to transform the object into a wireframe (i.e. see-through) or shaded model of the object. Unfortunately, these numbers are not commonly available from existing modeling programs [Burdea and Coiffet 1994]. Alternatively, the image of an object can be scanned into a computer. This image can then be cut and shaped to fit a polygon [Pimentel and Teixeira 1994]. Another approach for obtaining realistic objects is by importing the objects through Computer Aided Design (i.e. CAD) programs [Vince 1995].

The key to a virtual object's appearance is its surface reflectivity and texture. The surface reflectivity needs to take into account the position and type of light source. Depending upon this, the reflection of light off the object can be determined. The texture of an object can increase the level of detail and realism of a scene. Texture also can provide 3D spatial cues. This substantially reduces the number of polygons in the scene and as such, the refresh rate can therefore be increased [Burdea and Coiffet 1994]. The texture used by the objects can be created in several ways [Burdea and Coiffet 1994]:

- use a paint program to create and store the texture as a bitmap;
- use a photo of desired texture and scan the photo into the computer; or
- use a commercial texture database.

In order to simulate the surface smoothness of an object, the texture can also be simulated by a series of 3D patches where the height (z-dimension) of the objects characterises the surface roughness [Burdea and Coiffet 1994].

Finally, determining whether an object is static or dynamic should also be considered [Kalawsky 1993]. For

surface deformations, and etc, and as such, objects in the virtual world need to emulate these characteristics [Burdea and Coiffet 1994].

5.3 Object Behaviours

Some believe that the objects in the virtual environment must be realistic in order to provide a truer sense of immersion. Therefore, according to Vince [1995], any VR system must follow the rules of real physical simulation; that is, procedures used to animate virtual environments must have credible simulated behaviours. Another consideration is whether an object is dependant or in-dependant upon user inputs. For instance, a clock is not reliant upon any user inputs and can be modelled upon external sensors. Other virtual objects, however, have a degree of independence of user actions; that is a certain degree of intelligence. In these cases, the behaviour needs to be modelled by programming virtual reactions or reflexes [Burdea and Coiffet 1994].

The objects in the virtual world must be modelled physically [Vince 1995]. Thus, virtual objects need to specify their mass, weight, inertia, surface texture (smooth or rough), compliance (hard or soft) and deformation mode (elastic or plastic). These features can then be merged with the geometric modeling of the object and behavioural laws to form a realistic virtual model. The real physical constraints of objects also need to be modelled [Vince 1995]. For instance, a draw in a cupboard is limited in movement away from the cupboard. Thus, an object in the virtual world should be similarly constrained to limit translations and rotations about the axes of its local frame of reference. This can be set as parameters within the database and used to ensure that matrix operations transform the objects within the desired limits [Vince 1995]. Related to this, an object's weight should be centred on the object's center of gravity.

The issues of surface deformation and compliance need to be elaborated on. To simulate surface deformation graphically, each object in the virtual world needs to be 'meshed' and not represented as primitives [Vince 1995]. For example, a ball cannot be modelled simply by a sphere primitive. Each surface has to have meshed surface with the number of polygons determined by the desired level of detail and available graphics accelerators. So, for example, when squeezing a ball, the appropriate bulging is shown.

5.4 Building the Virtual Environment

The database of a VR system provides the content of the world. It has two aspects:

- content - a collection of facts and figures; and
- expertise - the accumulated understanding that has been gained through experience or study ; this represents the sum of what is perceived, discovered or inferred.

According to Larijani [1994], both content and the knowledge base (i.e. the expertise) are required for the development of effective VR applications. The designers of virtual environments need specific information for the virtual objects they build. The information held in the database is used both for building the virtual objects and environments, and for supplying information about those objects to the users in the virtual world. Databases are increasing complex, and as such, the user needs efficient interfaces and embedded intelligence (inference techniques) in order to interact with them [Larijani 1994]. Of prime importance is the real-time interaction capability [Mahoney 1995].

VR systems assembles pieces of the world by calculating how each polygon would look if viewed from a certain distance and direction. Next, all polygons are sorted so that the one furthest from user's viewpoint are drawn first. The entire process is repeated every time the viewpoint changes (e.g. moving a HMD in VR). Obviously, the number of polygons is crucial and this will influence the update rate that is possible [Pimentel and Teixeira 1994].

For realistic models and virtual environments, a large number of polygons are required; the more the number of polygons the more realistic the model. Rendering or drawing these polygons at interactive (and therefore real-time) rates is costly (if not impossible). In addition, the large memory requirements of this rendering may not fit into the random access memory allocation of the computer [Burdea and Coiffet 1994]. This will result in time-consuming movements between the rendering processes and the other memory locations (i.e. besides the random access memory). Therefore it becomes necessary for the developer to manage the world model in a better manner in order to maintain interactivity at reasonable rates. Several approaches to solve this problem have been proposed. This involves cell segmentation, variable detail and resolution display, offline pre-computation and memory management techniques [Burdea and Coiffet 1994].

For instance, cell segmentation is a technique which partitions the virtual world into smaller 'universes' or 'cells' [Burdea and Coiffet 1994]. This attempts to alleviate the problem with rendering large, complex imagery. Cell segmentation has the advantage that only the objects in the current 'universe' need to be displayed. This reduces the complexity of the world, significantly. Also, some of the object does not contribute at all to any given image, given that some of the object may be occluded by another object and that part of the object is behind itself.

The aim of a real-time interactive VR system is to have the system update rate running as high as possible. Showing only a certain level of detail is another interesting technique in which to reduce the image generation load. This strategy stores within the database, different levels of detail for specific objects. The different models are selected at appropriate times [Vince 1995]. Strategies for simulating such switching are based on distances from an observer's point of view [Burdea and Coiffet 1994]. Similar approaches can be applied to moving objects. Here, objects moving quickly are seen only for a short time and appear blurred and as such, it is not necessary to represent these objects in great detail [Vince 1995]. Rapidly moving objects can thus be

represented with just a few polygons [Burdea and Coiffet 1994]. However, by selecting different levels, a particular feature may be lost during the transition between objects of different levels of fidelity [Vince 1995].

According to Pimentel and Teixeira [1994], few VR systems have mastered the complexities of handling the real-time interactions and performing real-time texture mapping. The whole process is complicated, computationally intensive and requires specialised hardware. Thus, few 3D modelling tools understand the challenges of not only building the virtual worlds, but also efficiently managing a complex database of objects and attributes [Pimentel and Teixeira 1994]. High level object orientated techniques are ideally suited to modelling interactive VR systems [Kalawsky 1993]. Here, each object in the virtual world will have its own set of attributes and may be part of another object, grouped into some form of hierarchy. Parent attributes may even be inherited by the lower level objects. These techniques have the potential of alleviating some of the current problems with building virtual environments.

Mahoney [1995] also states that when building virtual worlds, it is better to use a top-down approach as opposed to a bottom-up approach; that is, one should consider the purpose of the environment and then start the modelling. Barfield et al [1995] also emphasis this view. So, for instance, in some situations accurate spatial orientation and location of objects is more important than detail and resolution. Also, when modelling real-world situations the laws of physics, for instance, need to be simulated as these give realism to the simulation [Mahoney 1995, Durlach et al 1992]. Finally, the success of a VR system is a function of the richness of the experience as a whole, and not the individual models [Mahoney 1995].

5.5 High Level Taxonomy

Zyda et al [1993] indicates that there are six aspects of the software phase that need to be considered. These are briefly discussed below:

- Interaction - the aim of these methods is to (i) take the raw data from the input devices and (ii) convert the data into a form which can be used by the system or application so that some meaningful operation is executed.
- Navigation - here, the main concern is how one moves through the 3D virtual world. Aspects such as the 3D input devices, the viewpoint of the virtual camera and methods for minimising polygon flow need to be considered. All of these aspects need to be coupled and achieved in real-time.
- Communication - passing changes in the world model to other players is the main concern here. Aspects such as database consistency and communication protocols needs to be considered.
- Autonomy - for many applications it is useful to have autonomous agents interacting with the real live agents. The issues of how these agents are developed and their integration into the virtual world is important.

- Scripting - this involves the ability of being able to record and playback the interactions.
- Hypermedia - this considers the possibility of allowing the addition of audio and still images into the 3D geometrically described virtual world.

As can be seen, there are many diverse software aspects that need to be considered when developing a complete virtual world.

5.6 Toolkits

5.6.1 Types

In the above sections, basic computer graphics terms, object representations and behaviours, and building virtual worlds have been discussed. As can be seen, if wishing to build from scratch a virtual environment to be used within a VR system, there are many issues which need to be resolved. An alternative method of building virtual environments is to use software products or toolkits which have already been developed. This section discusses some of these toolkits.

There are two major categories for the available VR software: Toolkits and authoring systems. Toolkits are programming libraries, generally in C or C++ that provide a set of functions with which a skilled programmer can create VR applications. Authoring systems are complete programs with graphical interfaces for creating worlds without resorting to detailed programming. These usually include some sort of scripting language in which to describe complex actions [Isdale 1993]. The programming libraries are generally more flexible than the authoring systems, but you must be a skilled programmer to use them [Isdale 1993]. The VR Sourcebook [1996] provides a good source of information of commercial companies.

Modelling toolkits have both shape libraries (with hold parametric definitions of circles, triangles, squares, arcs, ellipses, and polygons) and object library (with higher-level shapes such as cubes, spheres, cylinders) [Vince 1995]. Also, most toolkits have some sort of control language which is used to support all aspects of interaction, animation and physical (i.e. real) simulation [Vince 1995]. Toolkits are extendable libraries of object orientated functions. Libraries are extendable in that is it possible for developers to write application-specific modules and still use the simulation kernel [Burdea and Coiffet 1994]. Some VR Toolkits are hardware independent.

The aim of VR toolkits is to help programmers in system integration and application development. These are extremely useful tools and can cut programming time substantially. As these toolkits also accept CAD 3D files (dxf and others) this represents a significant reduction of development time by importing existing 3D object databases. Commercial packages support a large variety of high-end input/output tools, such as sensing gloves (DataGlove and CyberGlove), advanced graphics and networking for multi-user simulations [Burdea and Coiffet 1994]. Non-commercial toolkits support less expensive input/output devices, and have less performance

graphics. However, they are useful for proof-of-concept in initial research, as well as teaching the fundamentals of VR [Burdea and Coiffet 1994].

In summary, according to Moshell and Dunn-Roberts [1994], toolkits are useful as starting points for the construction of customized VR systems. They provide the following capabilities:

- tracking information from HMDs and other devices (such as gloves);
- stereoscopic displays;
- accepting CAD models; and
- the ability to have various degrees of physical modeling and detail control.

A survey of VR services and products (both hardware and software) was done by the AI Expert Journal in both 1994 and 1995. In 1994, this list contained a total of 14 pages, while in 1995, this list had increased 28% to a total of 18 pages [VR Resources 1995].

5.6.2 Available VR Software

The following contains some of the available VR software listed in alphabetical order:

AVIARY: This system was developed at Manchester University, United Kingdom and is available on Sun and SGI platforms. It is a multi-user virtual environment composed of loosely connected autonomous objects which execute concurrently [Kelly 1994].

DIVE: This was developed at the Swedish Institute of Computer Science and is available for the Sun and SGI platforms. It is an experimental interactive platform which provides a navigable shared 3D synthetic environment in which users can meet and collaborate. It supports the development of televirtuality, user interfaces and applications [Hand 1995, Kelly 1994].

dVS: Developed by Division Ltd (UK) for the SGI and IBM workstation platforms [Isdale 1993, Kalawsky 1993, Kelly 1994, Vince 1995, VR Resources 1995]. It is an environment which has actors that are responsible for various system activities - e.g. to support collision detection and audio. Each actor is responsible for a different function of the system. An actor may be a single process or a collection of processes that interact with the environment database. An actor is created to simulate a component of the virtual environment or to act as an interface to the real environment. Each actor can be freely created or deleted to perform a specified task and may have a limited life span. The cost of dVS ranges from $55,000 to $200,000 depending upon options [Buying Guide 1996].

GVS: Developed by Gemini Technology Corporation, GVS is a Generic Visual System. It produces an integrated virtual environment display which is needed to create discrete 3D objects and integrate them into an interactive visual display. There are several ways of doing this. An effective approach is to employ a 3D modeling package to create the virtual objects and devise a means of integrating these into a virtual world. GVS aims to produce a real-time visual simulated environment with minimal

levels of coding. The emphasis here, is on employing high level tools to provide a visual system that is connected to a distributed computing environment. When coupled with a 3D modelling tool, it is powerful software environment for creating and interacting with a virtual environment [Kalawsky 1993].

Humanoid: Developed by the Swiss Federal Institute of Technology, this is a real time and parallel system for the simulation of virtual humans including motion control, deformations and object grasping [Kelly 1994].

Jack: This human body simulation is a general purpose interactive environment for manipulating articulated geometric figures. Jack has the following aspects: hands, reaching, grasping, collision detection, collision avoidance, walking behaviour, balance control, field-of-view, joint torque and sensor channels. Jack can be used in conjunction with other simulation programs and can be measured for fit, reach, movement and etc. [Vince 1995, VR Resources 1995].

MRToolkit: Developed by the University of Alberta, this is a free programming library (to Universities and other research establishments) for UNIX systems [Hand 1995, Isdale 1993, Kalawsky 1993]. This Minimal Reality Toolkit (i.e. MRToolkit) is a subroutine library that supports the development of virtual environment and other forms of 3D interfaces. It provides basic services that are required to produce virtual environment user interfaces, as well as providing support for various devices such as the Polhemus Tracker and the VPL DataGlove. MRToolkit also supports the distribution of the user interfaces over multiple workstations, data distributed over several workstations, numerous interactive techniques and real-time performance analysis tools. It can be called from C programs on both SGI and DEC equipment [Kalawsky 1993].

MultiGen: This is an interactive tool for the creation and editing of visual system databases. MultiGen is a specialised Computer Aided Design (CAD) system, which emphasises things that are needed in real-time simulation; other CAD emphasis is on engineering aspects and artistic aspects (texture and shading) [Moshell and Dunn-Roberts 1994]. It is available on several platforms. This tool has become a standard for the flight simulation community. The ease in which sophisticated models can be developed for use in virtual environments offsets its high cost. MultiGen also allows a user to incorporate the Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED).

SmartScene: Developed by MultiGen Inc., this is an innovative rapid prototyping tool which can use a helmet and gloves to interactively constructed a virtual environment using intelligent models from a existing palette [Mlyniec and Mapes 1995, SmartScene 1995, VR News 1995]. This product is described below, in the section on innovative systems.

VEOS: Developed by the Human Interface Technology Laboratory at the University of Washington, VEOS is a UNIX based operating system shell which provides a comprehensive and unified management facility for generation of, interaction with

and maintenance of virtual environment [Isdale 1993, Kalawsky 1993, Kelly 1994]. It provides a user level framework for prototyping distributed applications. The underlying design of VEOS was to create a mechanism for specifying the tasks and assigning computational resources in a distributed design; it is written in LISP [Kalawsky 1993]. A VEOS application can be broken down into distinct processes which are as self-reliant as possible. VEOS is platform independent and has run on SGIs, Suns and DECs.

VRT: Developed by Superscape, VRT has dynamic features that mimic real objects (e.g. gravity, fuel, climbing, falling, etc) [Vince 1995]. VRT consists of several editors - the two important ones are Shape editor which provide interactive tools for building polygonal objects and World editor which organises the construction of virtual worlds from these objects [Vince 1995, VR Resources 1995]. This product costs $5000 [Buying Guide 1996].

World Tool Kit (WTK): Developed by Sense8, WTK is probably the most widely used product of this type. It runs on a wide variety of platforms from high end PCs to high end SGI boxes. It has won several awards for excellence [Hand 1995, Isdale 1993, Kalawsky 1993, Pimentel and Teixeira 1993, VR Resources 1995]. WTK costs $795 to $12,500 depending upon options.

WorldToolKit (WTK) is a library of C functions that can be used to write a C program for developing and interacting with virtual worlds. The user writes a C program referencing the functions, which then becomes a WTK application [Vince 1995]. WTK contains over 400 functions and a powerful simulation manager that allows rapid prototyping of custom applications. 3D models created with AutoCAD or any 3D modeller that generates dxf files can be read as objects [Pimentel and Teixeira 1993]. From a user's point of view, WTK provides a complete application development environment for synthesising virtual environment. One of its most attractive feature is its hardware independence.

As WTK is structured in an object oriented naming manner, it is easier to maintain visibility at a programming level of what is taking place. Its main classes are universe, object, polygon, vertex, path, sensor, viewpoint, light source, portal and animation. The universe is the uppermost class and only one can be active within the WTK virtual environment. A universe is built of objects, including sensors (external devices that provide input into the computer to control the position and orientation of objects such as mouse, tracker, etc), lights, animation sequences, portals, viewpoints, graphical objects, serial ports and others [Kalawsky 1993].

The user of WTK has to be a competent C programmer. However, this package is an excellent systems for those who want control over the creation of virtual environment at a detailed level and at a modest price. An effective method is to develop the application on a low cost PC and transfer the application to a high end workstation [Kalawsky 1993].

WorldUp: Developed by Sense8, this toolkit is based on Sense8's WorldToolKit (WTK) discussed above. WorldUp is a VR and visual simulation development tool that allows interactive world creation without the need for C programming. WorldUp's interactive development environment allows users to modify real time object behaviour and scene characteristics while the simulation is still running. Effects are seen straight away - there is no need to stop and re-compile. Also this toolkit includes tools for modelling, building and animating objects and environments. Also, 3D models created using many CAD packages can be imported [VR News 1995].

3D Builder: Even though this is not specifically a VR product, such products will influence the creation of the virtual environment. 3D Builder builds 3D models of real world data from photographs. It covers a wide range of custom modelling situations, from a single picture to projects (such as a large building or a city neighbourhood) that require a coordinated effort using dozens of pictures. A snap-to-grid axis is included, as is the ability to view the model both as entered and as calculated. Minimal, flexible measurements are needed, and in many cases, where there are natural x, y and z cues, no measurements may be necessary to create a 3D model. Using a comprehensive math solver, 3D builder is able to combine information from a large number of photos of large, complicated objects, extract information and merge it all together into a single 3D model ready to export to the target rendering program. This tool offers a variety of input formats including Photo CD, TIFF, JPEG, BMP, and Sun Raster. The tool can produce 3D dxf, IGES, 3D studio and Inventor VRML files [VR News 1995].

The VR resources guide [1995] listed several other interesting items, as listed below:

- CM research - add sensation of temperature.
- Coryphaeus Software - developed the Designer's workbench which can be used as an environment for creating and editing dynamic instrument displays and 3D VR scenes.
- Digital Media Group - uses StereoSynthesis which is a process which converts standard 2D film, video or still images to true stereoscopic 3D format.
- SimGraphics - computer generated characters.
- Thunderseat VR chair - originally developed for air combat trainers, this chair uses sound output to generate realistic vibratory sensations.
- Virtual Presence - uses the Genesis World Builder which is an interactive prototyping tool for use with WorldToolKit VR software. This tool gives the user the ability to manipulate objects, polygons, lights, sensors, path and so on in real-time.
- Virtus corp - uses Virtus VR which uses a drag-and-drop approach to world creation. Basic 3D shapes help build complex objects and structures. The tool provides the construction and navigation tools, galleries of 3D objects and pre-built scenes (PC and Mac only).
- Xtensory - produces tactile systems.

5.7 Final Comments

Kalawsky [1993] states that most aspects of VR rely on an underlying database standard on which to represent the objects in the virtual environment. In this manner, virtual environments are similar to Computer Aided Design (CAD). However, complete VR systems require a lot more to describe the environment. Of course the obvious geometrical and spatial relationship of objects are required. However, in VR, additional object information is required; information such as the texture, feel and compliance of an object needs to be specified. Also parameters, such as behaviour and interactions between objects, must be included. This must include the responses to external events or stimuli (such as collisions) and also should include the weight and feel of an object. Pimentel and Teixeira [1993] states that this is the fundamental problem with all 3D modelling; i.e. the developers of 3D models are only concerned with the visual representation of the objects. However, the object's physical properties, weight, center of mass, composition of, sound with contact with another surface, surface spongy or hard, rough or smooth are just some of the attributes which need to be included as part of the database for a VR system.

6. Innovative Systems

In this section several innovative systems are described. The first two, SmartScene and Polyshop, are interesting in that they used VR techniques to build terrain and/or visual databases. The Responsive Workbench and the Virtual Workbench, although quite similar, each have a different focus. These are systems which provide an workbench from which to work on. Finally, the CAVE system is described. The CAVE uses a room as its work space area. Imagery is displayed on three walls and the floor of this room.

6.1 SmartScene

The basis of SmartScene (developed by MultiGen) is that by placing identifiable pre-built elements, such as a building or a chair, in a scene is quicker and more efficient than having to build the elements from scratch. This obviously requires the availability of a comprehensive model library so that an appropriate model is available most of the time [Mlyniec and Mapes 1995]. SmartScene also uses ModelTime behaviours which are part of the models themselves and can be can be thought of as intelligent, three-dimensional "snap-to-grid" constraints [Mlyniec and Mapes 1995]. These behaviours are used to tell objects how to behave when they are being assembled with other such objects [SmartScene 1995, VR News 1995].

ModelTime behaviours bridge the gap between rough positioning and precision alignment [Mlyniec and Mapes 1995]. With no knowledge of the high-level relationships between objects in the scene, the snapping of vertices to other vertices in

the scene can be accomplished. Edge-to-edge and face-to-face alignment are also useful. These higher-level smart snapping relationships are stored with an object. So, for example, the second story of a building can seek out its first floor, ignoring the terrain, houses, and even other multi-story buildings of incompatible type [Mlyniec and Mapes 1995, SmartScene 1995, VR News 1995]. The result is a collection of seemingly magnetic objects which attract and repel in an intuitive fashion [Mlyniec and Mapes 1995]. Thus, it becomes a lot simpler and more intuitive to snap standard scene components together (particularly where the builder is disadvantaged by an HMD) because the precision alignments can be made to happen automatically, via the simulated magnetic attraction or repulsion between objects, vertices and faces [VR News 1995].

Scaling and stretching behaviours can also be triggered by the proximity of compatible objects during the construction of virtual environment. When an object is stretched, it may not be enough to uniformly grow it in the direction in which it is stretching. A stretch threshold is used to invoke a certain behaviour each time a certain stretch condition is met. For instance, stretching a building could have the effect of adding stories to it by repeating the geometry or texture appropriately, instead of simply stretching the one floor [Mlyniec and Mapes 1995]. This would seem to require some form of 'real' measurement to be incorporated.

During construction, the physical extent of an object can be used to support collision modelling. Gravity can also be used to manipulate objects in a scene if the objects are told to act under that force during a modelling session. Objects with mass, moment of inertia, flexibility, and so on can further enable the builder to treat the assembly of a synthetic scene as the everyday manipulation of familiar elements [Mlyniec and Mapes 1995].

The rapid prototyping technique discussed so far has an inherent drawback; it is difficult to create scenes that do not look repetitive even with an extensive model library [Mlyniec and Mapes 1995]. By building smart palettes into the models, that is attribute palettes designed specifically for the object, variety can be attained through multiple choice [Mlyniec and Mapes 1995].

ModelTime behaviours is well suited to immersion [Mlyniec and Mapes 1995]. A stereoscopic 3D HMD immerses the builder in a 3D visual work space and a two-handed Fakespace Pinch Glove interface puts 3D widgets, model components, texture and colour in the palm of the hand [SmartScene 1995, VR News 1995]. Natural hand gestures can then be used to grab and manipulate the scene components with one or both hands. The task of positioning, scaling and rotating are done in a single, natural hand gesture. The advantage of this system is that it exploits the natural human usage of their hands. Figure 10 has an interesting view of SmartScene.

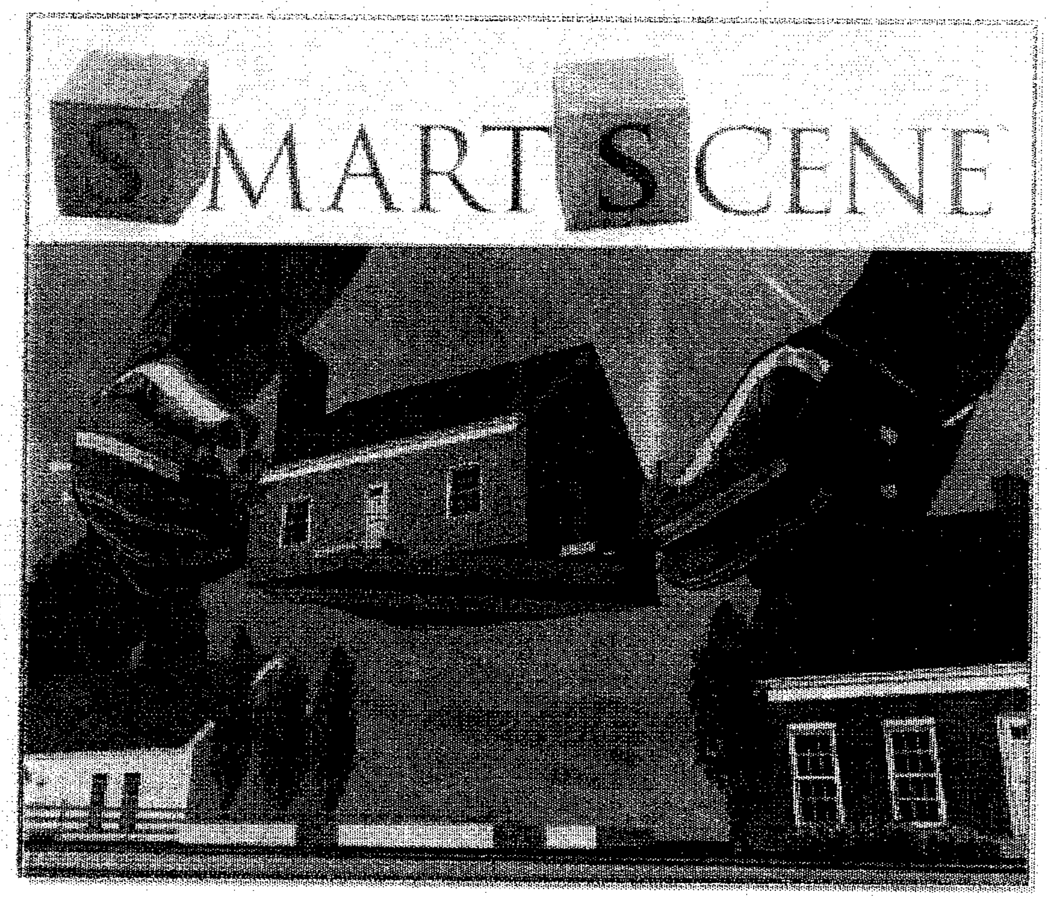


Figure 10: The SmartScene tool from MultiGen (adapted from [SmartScene 1995]).

6.2 PolyShop

PolyShop is a research project at the Institute of Simulation and Training (IST) based in Florida, USA [Abel et al 1995]. It is focussed on the construction of 3D visual database using VR. Its objective is to examine and develop a networked multi-user, 3D immersive user interface for the rapid construction of urban databases [Abel et al 1996]. The network's purpose is to allow multiple participants to work on the same database simultaneously at remote locations. VR technology provides the 3D immersion and the interactive stereoscopic vision. This enables the modellers to have a more intuitive spatial orientation and perspective of the objects they are building.

The modeller sits at a desk. The top of the desk is reproduced in the virtual world with virtual buttons, sliders and controls added to it. For geometric modeling, the user sits at a drafting table style desk constructed to minimise interference with the trackers.

The physical and virtual desktop are calibrated so that the virtual one mirrors the real one. Different tools are also modelled. The modeller is immersed with a HMD and gloves for object and tool manipulation. Sound feedback is used to make interactions better; sound is used for indicating the proximity of an object.

The main aim of PolyShop is to have a shared virtual environment where several modellers at different locations can collaborate simultaneously on same graphical database. PolyShop uses enhanced Distributed Interactive Simulation (DIS) protocols for communication and modelling a particular world. Standard DIS is not able to send dynamic data across network. The developers of PolyShop have proposed a geometric state PDU (basic database changes over DIS network in real-time) [Abel et al 1995].

The manipulation of the virtual objects and control is done with a two handed interface, based on ChordGloves. These gloves were developed at the IST. These ChordGloves are used to manipulate the objects in PolyShop's 3D virtual space. Glove manipulations are an intuitive interface for humans [Abel et al 1995]. Also different hand gestures can be used to perform different actions.

The modeller grabs an object in 3D using both gloves and then selects the desired action (e.g. scale, stretch) and then shapes it in the required way. Texture and colour can be added to the objects, as well as glueing objects together. From this, a complex database can be constructed. This is a powerful 3D modelling interface [Abel et al 1995].

A Polhemus FasTrak trackers with three sensors is used to track the head and both hands. A low cost HMD is used for the immersive stereo display. Sound feedback and voice input enhances interactions and adds versatility to the tool. However, both require dedicated PC boards. For the sound feedback, specific events give specific sounds in order to provide additional feedback. Voice recognition module receives input from a microphone and produces an encoded command (e.g. stretch, colour, etc).

The software of PolyShop is written on top of WorldToolKit (WTK - see above). WTK handles the simulation loop, sensors and basic object organisation. The software has two distinct layers [Abel et al 1995]:

- First layer has the following characteristics (a) unique VR software which includes a manipulation metaphor, (b) direct mapping between virtual and physical worlds, (c) fatigue is decreased for reaching objects by allowing an application to be built around a physical desktop and (d) has precision object alignment operations.

- Second layer is the widget toolkit layer which is totally dependant upon the first or VR baseline layer. This toolkit has an array of useful tools, including a chooser for bringing models into the world, light, colour changes, menus and trashcans.

PolyShop can be run on a stand alone workstation or networked allowing multiple participants to interact with same database through Ethernet serial communications. The initial product was prototyped on a PC; it is currently being ported to SGIs

workstations. It can also be run with different hardware configurations and a range of operation modes. The base level is a keyboard mode with a single window, while an advanced level uses full immersion with a HMD and gloves [Abel et al 1995].

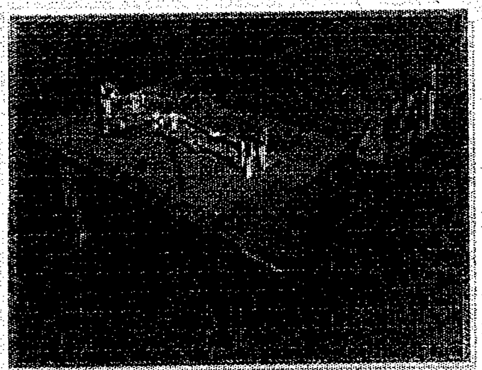
6.3 Responsive Workbench

The "Responsive Workbench" concept is a system where the user no longer experiences simulations of the world on the computer. Instead, the computer is integrated into the user's world in a way which is not seen by the user. To enhance the illusion, common everyday objects and activities become the inputs and outputs for this environment [Bleicher and Heiden 1995]. This concept was pioneered by W. Kruger from Germany [Bleicher and Heiden 1995]. The responsive workbench has been duplicated at the Naval Research Laboratory, USA [Durbin 1995].

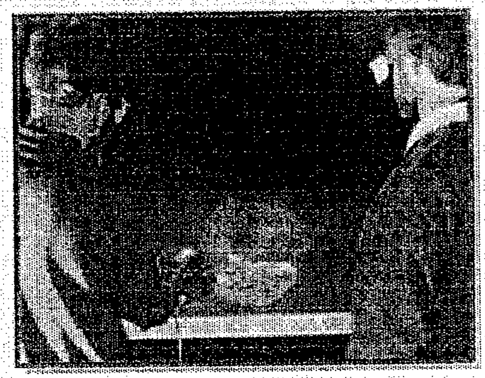
The Responsive Workbench is a 3D interactive graphics system where computer-generated stereoscopic images are projected onto a tabletop via a projector-and-mirrors system. The user of the workbench wears shutter glasses to observe the 3D effect. A tracking system tracks the user's head and hand positions to allow interaction with objects in the tabletop environment [Bleicher and Heiden 1995, Durbin 1995, Kruger et al 1995]. Other participants can also interact in the shared virtual environment and shared physical place; however, only one participant is tracked [Durbin 1995].

Virtual objects and control tools are located on a real workbench. The objects displayed as computer-generated stereoscopic images are projected onto the surface of a table. This can correspond to the actual work situation of, for example, an architect's office or a surgeon's operating table. A guide uses the virtual working environment while several observers can watch events through shutter glasses. The several observers can work together locally or use global communication networks [Bleicher and Heiden 1995].

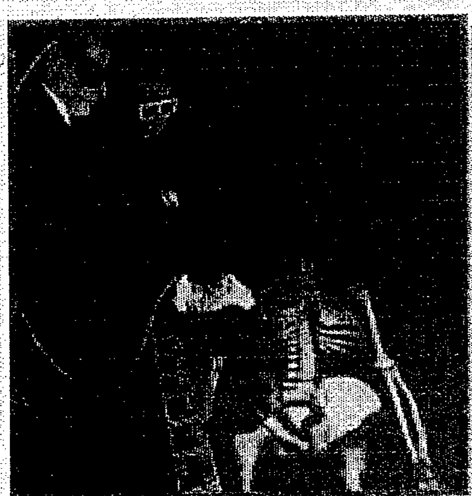
The Responsive Workbench's physical hardware consists of a projector, a mirror, a translucent table top and the LCD shutter glasses are StereoGraphics' CrystalEyes [Durbin 1995]; see Figure 11. The German version of the workbench uses a CyberGlove and the Polhemus' Fastrak sensors for head and hands tracking [Kruger et al 1995], while at the Naval Research Laboratory, locally developed gloves and the Polhemus' 3SPACE tracker system are used [Durbin 1995]. The software used is the SGI Graphics Library (GL), the Performer software, Hark voice recognition system and the SVE software package [Kruger et al 1995].



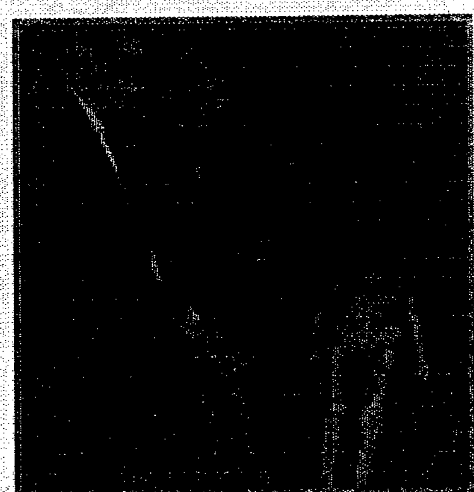
Stereoscopic display of virtual objects on a table



Examination of the blood flow in a human heart



In the scenario, a physician picks up a bone with the glove device



Cooperative work scenario of a physician and a student

Figure 11: The Responsive Workbench and some of its usages [adapted from Krueger et al 1995].

The following applications have been developed for use with the Responsive Workbench:

- non-sequential medical training (the scenario is based on a real sized model of a patient, who could be examined in any detail through the zooming operation; also important in this application is the dynamic aspects, like the beating heart and the blood flow inside of the body);
- surgery planning;
- the fluid dynamics visualisation in a virtual windtunnel; and
- the three-dimensional simulation of design in architecture and landscape planning.

Figures 11 shows some of these applications [Kruger et al 1995].

6.4 Virtual Workbench

Although the system known as the Virtual Workbench is similar to the Responsive Workbench described above, the focus of this Workbench is quite different. It main goal is to produce a work environment in which delicate work can be performed for long hours without any strain [Poston and Serra 1994, 1996]. This is achieved by embedding the virtual world in the user's natural work volume.

The natural work volume is represented by a region of a foot or so in front of the eyes; this is for precise, comfortable depth perception and within easy reach of both hands [Poston and Serra 1996]. The human's hand-eye coordination ability is used to achieve dexterity in this natural work volume. Here, the user both feels where something is (through their own hand holding something) and seeing it in the virtual space. In this case, the something is a generalized tool handle. However, what the user sees in the virtual space is a virtual tool (such as a cutter or pencil), which the software creates. Thus, the user feels where the hand is and where the physical tool is, and this matches the virtual tool in the virtual space [Poston and Serra 1994]. The calibration between the tool handle and the virtual tool is obviously important [Poston and Serra 1994, 1996]. It is also interesting to note that only the handle is modelled; the actual hand holding the handle is not [Poston and Serra 1996].

The Virtual Workbench, shown in Figure 12, consists of a computer screen, a pair of stereo glasses (Crystal Shutter Glasses), a mirror and one or more 3D position and orientation sensors which are on some sort of handle (i.e. are grippable) [Poston and Serra 1994, 1996]; an example of such a sensor is the Immersion Probe ™ . Haptic devices to provide force feedback are also being considered. The virtual image within the work volume is perceived by the user by looking through both the mirror and the glasses. Currently, the Virtual Workbench is based on a SGI Reality Engine; however, a version based on a high-end PC is currently being developed.

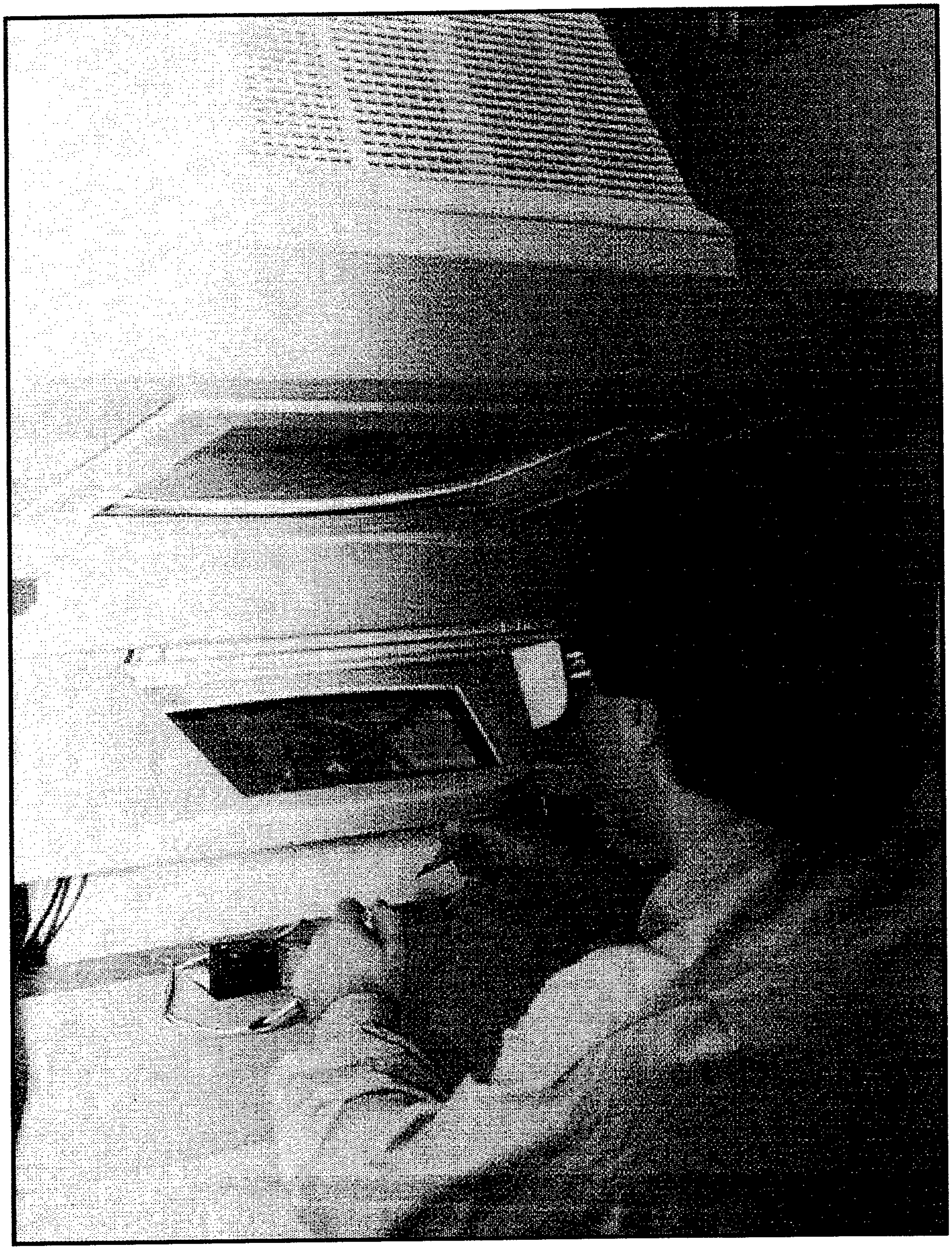


Figure 12: The Virtual Workbench [adapted from Poston and Serra 1994].

The Virtual Workbench supports both fixed and head-tracked viewpoints [Poston and Serra 1996]. Fixed viewpoints are useful for objects within the natural work volume. However, this is not sufficient for judging the proximity of an object which is perpendicular to the user. A head-tracked viewpoint is useful here and in high precision work where a slight movement of the head can help estimate the proximity of an object. In order to evaluate the performance and ergonomics of this system, a dexterity test was developed. This showed that stereo vision and head-tracking are important [Poston and Serra 1996, 1994].

To date, this Virtual Workbench has been primarily used in medical applications. Some of these are listed below:

- visualisation tools for diagnostics [Poston and Serra 1996];,
- contour editor showing the heart walls [Poston and Serra 199];,
- tube finder for identifying blood arteries [Poston and Serra 1996, Poston et al 1995]; and
- heart disease assessment [Solaiyappan et al 1996].

6.5 CAVE

The main objective of CAVE (Cave Automatic Virtual Environment) is to develop a visualizsation tool which can be used by scientists [Cruz-Neira et al. 1993a]. Also, the developers of the CAVE wanted to illustrate that the correct projection of the imagery on large screens can also create a VR experience. CAVE stresses that projection technology achieves a system that matches the quality of the workstation in terms of resolution, colour and flicker-free stereo [Cruz-Neira et al. 1993b].

CAVE uses multiple large projection displays to create a room in which the viewer(s) stand [Isdale 1993]. CAVE uses stereoscopic video projectors to display images on three surrounding walls and on the floor. Projectors display full-colour workstation fields (i.e. 1280x512) at 120Hz onto the screens [Cruz-Neira et al. 1993b]. The use of multiple projection systems can provide immersive displays that cover the entire visual field with many pixels, but increasing the number of screens also increases the requirements for computing graphics [Boman 1995]. The illusion of immersion is thus created by projecting stereoscopic computer graphics into a cube composed of display screens that almost completely surround the viewer [Cruz-Neira et al. 1993a]. The CAVE and its arrangement of the projectors is shown in Figure 13 [Lewis 1994].

The participants wear glasses with LCD stereo shutters to view the 3D images in the CAVE. Multiple participants can be in the CAVE at any time. However, only one participant is tracked and the 3D images are referenced to that person's position [Boman 1995, Kelly 1994, Vince 1995]. That person's head and hands are tracked with Polhemus or Ascension devices. Four SGI high-end workstations (i.e. Onyx) create the imagery (one for each screen).

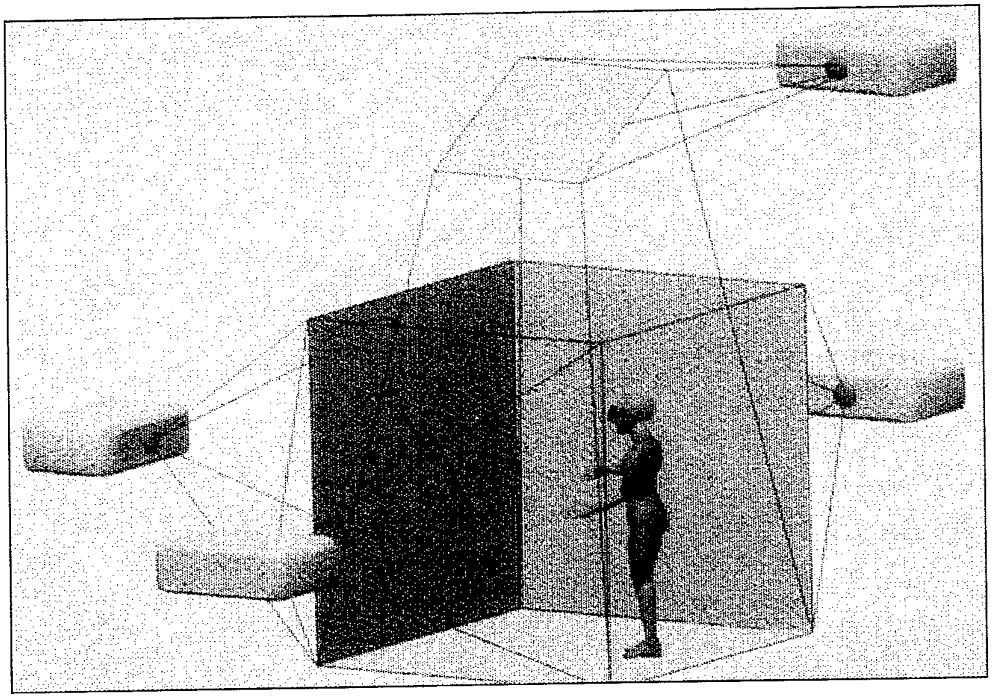


Figure 13: The CAVE architecture with the four projectors
(adapted from [Lewis 1995]).

The CAVE blends both real and virtual objects in the same space. People in the CAVE have an un-occluded view of their own bodies as it interacts with the virtual world and the objects within it. They are also aware of the real surroundings. This removes the possibility (and fear!) of walking into a wall. So, the CAVE is an non-instrusive environment where the real and virtual worlds are naturally combined [Cruz-Neira et al. 1993a].

Some of the goals of CAVE's engineering effort include [Cruz-Neira et al. 1993b]:

- desire for high resolution colour images without geometric distortion;
- less sensitivity to head-rotation induced errors; and
- ability to mix VR imagery with real devices (such as a human's hand).

CAVE has primarily been used for exploring visualisation of precomputed databases [Cruz-Neira et al. 1993b, Vince 1995]. For instance, the CAVE has been used to visualise a human brain model [Boman 1994]. The use of the CAVE in medical research has great potential as it can translate what is seen in a microscope into a larger-than-life representation [Lewis 1995]. Other applications include [Cruz-Neira et al. 1993a]:

- architectural walk-through;
- visualisation of the molecular dynamics of cancer;
- exploration of the cosmos;

- regional scale weather display; and
- modeling superconductors on massively parallel computers.

The shortcomings of the CAVE are as follows [Cruz-Neira et al. 1993b]:

- large and expensive;
- six screens would have been better, but entry and exit would be a problem;
- light reflection from various screens; and
- directional sound is not achieved due to reflections off the screens.

The developers of CAVE believe that it has great potential. They have achieved their goal of producing a large field-of-view, creating high resolution full-colour images and allowing multi-person presentation format. A smaller, less expensive version of the CAVE, called ImersaDesk, is currently being developed [Lewis 1995].

7. Applications

Jacobson [1991] states that VR can be used in any commercial field where people use computers to store, manage, manipulate, analyse, present and want to understand complex data. As such, VR has numerous applications. The Japanese have already employed immersive systems for showing products to home-buyers building new kitchens [Kahaner 1994]. Some countries in Europe have used VR for manufacturing and designing new user interfaces [Encarnacao and Gobel 1994]. One organisation in the United States is using VR techniques for the automatic 3D construction from image sequences [Kelly 1994]. Also, the VR developing hardware and software can enhance existing simulator systems. In particular, the rapid prototyping toolkits, such as WorldToolKit and SmartScene, have the potential of improving productivity. NASA's 1993 White Paper listed several applications of VR [Null and Jenkins 1993]; this document highlights many applications ranging from scientific visualisations to training systems, as well as speculating about future VR applications.

In this section, a brief list of some of the current applications in VR will be presented. Firstly, VR applications in general will be presented. After this, VR applications in defence will be given.

7.1 General Applications

Boman [1994] has a useful taxonomy of classifying VR applications. This taxonomy is used below to classify some of the current applications of VR:

Education and training:

- training astronauts and flight controllers on extravehicular activities for space missions (weightlessness is simulated) [Boman 1995];

- training flight crews on the operation of the Space Shuttle's Remote Manipulator System Robot Arm [Boman 1995];
- virtual science laboratory where the student can control gravity, friction and time [Boman 1995]; and
- training disabled children to control motorised wheelchairs [Boman 1995].

Design and testing:
- testing the visibility of different tractor designs [Boman 1995];
- automobile manufacturers testing new dashboards [Boman 1995];
- testing new aircraft designs [Boman 1995];
- industrial security systems [Nomura 1994];
- architectural walk-throughs [Encarnacao and Gobel 1994, Moshell and Dunn-Roberts 1994];
- software tools [Null and Jenkins 1993];
- driving simulations [Bayarri et al 1994];
- advanced interfaces [Encarnacao and Gobel 1994];
- rapid prototying of terrain databases [Polis et al 1995]; and
- manufacturing (i.e. designing new products] [Nomura 1994].

Information visualisation:
- scientific visualisation [Bryson 1996, Null and Jenkins 1993];
- computational fluid dynamics (i.e. Virtual Wind Tunnel) for air flow over aircraft wings [Moshell and Dunn-Roberts 1994, Jacobson 1991];
- planetary exploration [Null and Jenkins 1993];
- visual analysis of software which automatically control complex power networks [Boman 1995]; and
- viewing images from a scanning, tunnelling microscope [Boman 1995].

Medicine:
- ultrasound image superimposed on live video (X-ray vision) [Boman 1995];
- providing greater interactivity to people with severe disability through computer interfaces that use eye movements and muscle potentials [Boman 1995];
- virtual glass elevator to treat acrophobia [Boman 1995];
- robot assisted surgical system;
- planning of radiation therapy [Moshell and Dunn-Roberts 1994]; and
- health care [Nomura 1994, Null and Jenkins 1993].

Other areas include the applications in augmented reality (where the computer generated imagery is combined with the view of the real world) and telepresence (where one can remotely manipulate equipment at a remote site) [Boman 1995, Moshell and Dunn-Roberts 1994].

7.2 Defence Applications

In defence, VR has great potential. According to Baumann [1995], there are three types of military training and applications:

- simulation of reality;
- extension of human senses through telepresence; and
- information enhancers through augmented reality.

In the area of military simulations, multiple monitors are used to simulate the entire field-of-view from an aircraft cockpit [Baumann 1995]. This is a simulation of reality type of application. This type of application is commonly used for transport aircraft. Fighter aircraft simulations, on the other hand, need 180 degrees both in horizontal and vertical. A common configuration has a cockpit placed in the center of a domed room, with virtual images projected on the inside surface of the dome. An example of such a configuration is the Air Operations Simulation Centre (AOSC) partial dome [Feik and Mason 1993a, Feik and Mason 1993b]. In addition, Distributed Interactive Simulation (DIS) communication protocols can be used to connect several simulators. This type of configuration can be used for training as well as developing and testing new combat strategies and tactics.

Telepresence can be defined as a medium that gives a person the sense of being placed physically within remote, computer-created scenes [Larijani 1994]. This is extremely useful in military applications because the exposure to hazards is reduced. In addition, stealth is increased dramatically. Smart vehicles and remotely-piloted vehicles were developed for this [Baumann 1995].

Augmented reality is a system which combines both real and virtual views. In the dynamic combat environment, it is necessary to give the pilot all necessary information (such as airspeed, altitude, heading and location of enemy aircraft). This need led to the development of a Head Up Display (HUD) which optically combines critical information with an unobstructed view through the forward viewscreen [Baumann 1995].

In 1993, Webb [1993] considered the applications of VR to Army Training. Some of the areas identified as possibly benefiting from VR technologies were live firing, parachuting, artillery, infantry, and transport.

The following is a list of military applications using VR:

- simulating real-world combat scenarios [Alexander 1993];
- mission planning and rehearsal [Moshell et al 1995];
- training [Durlach et al 1992];
- training nuclear submarine crews [Alexander 1993];
- training aircraft pilots [Alexander 1993];
- parachute training [Pettersen 1993];
- Stinger missile training [Kelly 1994];

- VETT (Virtual Environments Technology for Training) - US Navy project [Durlach et al 1992];
- Officer-of-the-watch training (MARS VRS) [TTCP/SGU 1996];
- Hubble Space Telescope Repair Training System [TTCP/SGU 1996];
- tele-operations [Moshell and Dunn-Roberts 1994, Kelly 1994]; and
- aircraft marshalling (at Standford Research Institute SRI) [Webb 1993].

8. Current Research

The requirements of VR are large, and there are many broad areas in which research is being carried out. A useful taxonomy of research area was given by Boman [1995] and this is listed below:

- displays for presenting information to the user's visual, auditory and haptic senses;
- sensors and other technologies for transferring information from user to computer;
- software;
- human factors; and
- applications.

In this report, only the research being carried out in sensors and displays, and software will be presented.

8.1 Sensors and Displays

In the area of displays and sensors, the following is a short list of some of the current activity:

- innovative optics and imaging techniques for improving HMDs [Moshell 1995];
- improving haptic interfaces to improve the sensation of feeling and touching through tactile and force feedback sensations [Moshell and Dunn-Roberts 1994, Boman 1995];
- developing improved tracking systems for tracking the user's head and hands position and orientation more accurately and faster as well as being able to track other objects in the virtual world [Moshell and Dunn-Roberts 1994];
- development of a bodysuit which tracks the bend in the various joints on the human body [Kelly 1994];
- development of a visual display system which projects an image directly onto the retina using scanning laser beams [Moshell and Dunn-Roberts 1994, Boman 1995];
- improving image generators to reduce the latency problem (i.e. the delay between a change to the visual database or viewing parameters to the change in the display) [Moshell and Dunn-Roberts 1994];
- enhancement of VR realism by considering stereoscopic visuals, physical properties of objects and their interaction [Kelly 1994];

- improving the illusion of immersion by attempting to satisfy all human senses [Barfield et al 1995, Kelly 1994]; and
- improving 3D acoustics displays [Boman 1995, Encarnacao and Gobel 1994, Kelly 1994]. Here, the requirement is for a complete 3D sound environment where sound is spatially localised, can be attached to virtual objects and can maintain their location as a participant move through the environment [Boman 1995].

8.2 Software

According to Moshell and Dunn-Roberts [1994], the main aim of the software of a VR systems is to maintain a real-time model of the virtual world and to be able to maintain the interactions between the virtual objects. Besides this high speed graphics, rendering the images is also crucial [Boman 1995, Pratt et al 1995]. In the past, a lot of research has been carried out in making computers ran better in real-time; this was due to the development of the flight simulator.

Different generic approaches to the construction of the virtual environment have been proposed by several researchers. One approach separates the maintenance of the simulation environment from the rendering of the graphical database [Boman 1995]. Appino et al [1992] presented a different approach for the creation of an interactive, real-time, 3D simulation. They organised the individual elements into three main areas of device servers, application knowledge and dialogue manager. These three processes are modelled as a collection of independent processes which communicate by message passing [Appino et al 1992]. Another slightly similar approach separates the construction into two layers or areas; one layer supports input devices, communications and knowledge about the geometrical shape while the another layer organises the virtual environment along the principles of the real world [Boman 1995].

The following is a short list of software research being carried out which will have a direct bearing of VR:

- 3D imaging [Kelly 1994];
- sound features (i.e. which sound should be produced and is it necessary to have an extensive sound library) and the resulting sound of various objects (say a glass and a table) interacting;
- distributed interactive simulation (DIS) protocol for communicating between various computers (which includes the dead reckoning algorithms which allows a simulator to make a local approximation of the position and velocities of all other simulated entities) [Moshell and Dunn-Roberts 1994, Stytz et al 1995];
- interoperability which investigates mechanisms for communicating across computers through the DIS protocol [Moshell et al 1995, Stytz et al 1995];
- dynamic terrain (i.e. algorithms to support an outdoor environment which changes according to events such as bomb blasts) which include soil and hydrology models [Moshell et al 1995, Moshell and Dunn-Roberts 1994];
- intuitive interfaces [Boman 1995, Kelly 1994];

- physical simulation (i.e. animation of humans and animals) [Moshell and Dunn-Roberts 1994, Kelly 1994];
- automated and semi-automated forces [Kelly 1994];
- construction of 3D visual terrain database using satellite imagery and image sequences [Encarnacao and Gobel 1994];
- computer modelling, animation and rendering techniques with focus on rendering and control of virtual humans (JACK);
- environmental and terrain modeling [Polis et al 1995],
- mission rehearsal [Moshell et al 1995]; and
- rapid prototyping [Polis et al 1995].

9. Conclusions

The aim of this report was to familiarise the reader with the key areas of Virtual Reality (VR). VR is an encompassment of an environment (visual, audio, haptic), plus the humans within the environment, plus the interfaces between the two. Therefore, a description of VR needs a description of both human senses, and computer hardware and software technologies. This report also described several innovative systems, applications and the focus of current research.

Satisfying the human senses is a large part of VR. Many developers of VR systems indicate that the major stumbling block at the moment is the inadequacy of the haptic or feeling devices. These devices are supposed to give feedback to the user from the objects inhabiting the world; this feedback needs to be both tactile (i.e. texture and feel of an object) as well as the force feedback (i.e. mass of an object).

The area of VR is very broad, as it encompasses many aspects. As such, the developments of VR has an impact in many areas. Obviously, the development of new hardware and software technologies has an impact in many other areas such as flight simulation, software development and human factors. VR enforces that being in an immersive environment and therefore being able to interact with the environment, will lead to new insights. This is definitely the case where VR is being used to visualise numerical data. By seeing the virtual world from within, new perspectives and therefore, new discoveries, can be made. In addition, the reconfigurable nature of VR systems is more cost-effective, than say, building another simulator or building a mock-up of a virtual world [TTCP/SGU 1996]. As well, the testing of new equipment prototypes is fairly straightforward in the virtual world as virtual mock-ups are easier to modify than real hardware.

Of the existing application areas, the possibility of using VR technologies for the construction of visual databases for both military and civilian applications is intriguing. The construction of visual databases in currently very time-consuming. The two systems, known as SmartScene and PolyShop, propose interesting solutions to this problem. They both use immersive technology to construct a virtual world. SmartScene puts the user into an initially empty virtual world; from here, the user is

then able to construct the virtual world by selecting objects from a object palette. These objects have some "intelligence" which prevents, for example, placing a tree onto a road. PolyShop attempts to exploit the Distributed Interactive Simulation (DIS) communication protocol in order to have several modellers interacting and constructing the same virtual world. These modellers also use an object palette and two handed gloves by which to construct a virtual world. The potential time saving of these systems is enormous.

One of the problems identified in the VR area [Kalawsky 1993, Moshell and Dunn-Roberts 1994, Alexander 1993] is that there exists no universally accepted hardware and software standards. This has the affect of negatively affecting transportability and compatibility [Alexander 1993]. If in the future, virtual worlds are to interact across networks, for instance, using the DIS communication protocol, then standards and interoperability aspects need to be sorted out.

10. References

[Abel et al 1995] Abel K., Alic M. and Moshell J., "Rapid Construction of Model Building for Urban Combat Mission Rehearsal Databases (PolyShop)", Final Report, Institute of Simulation and Training (IST), Florida, April 28, 1995; http://www.vsl.ist.ucf.edu/~polyshop

[Alexander 1993] Alexander D., "Military Applications for Virtual Reality Technologies", Military Technology MILTECH 5/93, pp 54-57

[Appino et al 1992] Appino P., Lewis J., Koved L., Ling D., Rabenhorst D. and Codella C., "An Architecture for Virtual Worlds", Presence, Vol. 1, No. 1, Winter 1992, 1-17

[Asch 1992] Asch T., "Designing Virtual Worlds", AI Expert, August 1992, 23-25

[Aukstakalnis and Blatner 1992] Aukstakalnis S. and Blatner D., Silicon Mirage: The Art and Science of Virtual Reality, Edited by S. Roth, Peachpit Press, 1992

[Barfield et al 1995] Barfield W., Hendix C., Bjorneseth O., Kaczmarek K. and Lotens W. "Comparison of Human Sensory Capabilities with Technical Specifications of Virutal Environment Equipment", Presence, Vol. 4, No. 4, Fall 1995, 326-356

[Baumann 1995] Baumann, "Military Applications of VR", http://www.cs.umd.edu/projects/eve/eve-articles/military, 1995

[Bayarri et al 1994] Bayarri S., Fernandez M. and Perez M., "Real-time Graphics and Virtual Reality for Driving Simulation in Urban Environments", Proceedings of Virtual Reality Software and Technology (VRST'94), August, Singapore, 1994

[Bleicher and Heiden 1995] Bleicher A. and Heiden W., "The Responsive Workbench", http://viswiz.gmd.ge/VMSD/Pages.en/projects/workbench.html

[Boman 1995] Boman D., "International Survey: Virtual-Environment Research", IEEE Computer, 57-65, June 1995

[Bryson 1996] Bryson S., "Virtual Reality in Scientific Visualisation", Communications of the ACM, May '96, Vol. 39, No. 5, 62-71

[Bryson and Feiner 1994] Bryson S. and Feiner S.(Chairs), "Research Frontiers in Virtual Reality", SIGRAPH'94, Computer Graphics Proceedings Annual Conference Series, 473-474, 1994

[Burdea and Coiffet 1994] Burdea G. and Coiffet P., Virtual Reality Technology, John Wiley and Sons, 1994

[Buying Guide 1996] Ian's VR buying guide, May 1996, http://www.cs.jhu.edu/~feldberg/vr/vrbg/html

[Cruz-Neira et al. 1993a] Cruz-Neira C., Leigh J., Barnes C., Cohon S., Das S., Englemann R., Hudson R., Papka M., Siegel L., Vasilakis C., Sandin J., DeFanti T.,

"Scientists in Wonderland", http://www.ncsa.uiuc.edu/EVL/docs SHOWCASE/cave/vrpaper : also Proceedings IEEE Symposium on Research Frontiers of Virtual Reality, San Jose, California, October 1993

[Cruz-Neira et al. 1993b] Cruz-Neira C., Sandin D. amd DeFanni T., "Surround-Screen Projection-Based Virtual Reality: the Design and Implementation of the CAVE", SIGRAPH 1993 paper, http://www.eecs.uic.edu /~ccruznei/sig93.paper.html

[Durbin 1995] Durbin, J., NRL-VRLAB,1995,http:// www.ait.nrl. navy.mil/vrlab/pages/ workbench.html

[Durlach et al 1992] Durlach N., Pew R., Aviles W., DiZio P., Zeltzer D., "Virtual Environment Technology for Training (VETT)", BBN Report No. 7661, Naval Training System Center, Naval Warfare Center, Orlando, Florida, March 1992.

[Ellis 1994] Ellis S., "What are Virtual Environments?", IEEE Computer Graphics and Applications, January 1994, pp 17-22

[Encarnacao and Gobel 1994] Encarnacao J. and Gobel M., "European Activities in Virtual Reality", IEEE Computer Graphics and Applications, 66-74, Jan. 1994

[Feik and Mason 1993a] Feik R. and Mason M., "The Use of Simulators to Improve Air Operations and Acquisitions in Australia", SITRA '93, Bundang, Indonesia 27-29 July, 1993

[Feik and Mason 1993b] Feik R. and Mason M., "A New Simulation Facility for Research in Military Air Operations", Fifth Australian Aeronautical Conference, Melbourne, 13-15 September, 1993

[Hand 1995] Hand, C., "VR Software", 1995, http://www.cms.dmu.ac.uk/People/ cph/vrsw.html

[Isdale 1993] Isdale, J., "What is Virtual Reality", 1993, http://www.cms.dmu.ac.uk /~cph/VR/whatisvr.html

[Jacobson 1991] Jacobson L., "Virtual Reality : A Status Check", AI Expert, August 1991, 26-33

[Kahaner 1994] Kahaner D., "Japanese Activities in Virtual Reality", IEEE Computer Graphics and Applications, 75-78, Jan. 1994

[Kalawsky 1993] Kalawsky R., The Science of Virtual Reality and Virutal Environments", Addison-Wesley, 1993

[Kelly 1994] Kelly D., "Virtual Reality Links", http://www.dsg.cs.tcd.ie/dsg/people/ dkelly/vr.html

[Krueger et al 1995] Krueger W., Bohn C., Frohlich B., Schuth H., Strass W. and Wesche G., "The response workbench: a virtual work environment", IEEE Computer, 42-48, Vol. 28, No. 7, July, 1995

[Larijani 1994] Larijani L, The Virtual Reality Primer,McGraw-Hill, 1994

[Lavroff 1992] Lavroff N., Virtual Reality Playhouse, Waite Group Press, 1992

[Lewis 1995] Lewis R., "Virtual Reality brings Scan Data to Life", Photonics Spectra, July 1995, 40-42

[Mahoney 1995] Mahoney D., "Modeling for Virtual Reality", Computer Graphics World, October 1995, 45-50

[McDowall 1994] McDowall I., "3D Stereoscopic Data for Immersive Displays", AI Expert, May 1994, 18-21

[Mlyniec and Mapes 1995] Mlyniec P. and Mapes D., "Increased Productivity through ModelTime Behavior", The Engineering Reality of Virtual Reality, eds. M.T. Bolas and S.S. Fisher, Proc. SPIE 2409, 1995

[Moshell and Dunn-Roberts 1994]	Moshell J. and Dunn-Roberts R., "A Survey of Virtual Environments: Research in North America Part II", Virtual Reality World, January/February, pp 24-36, 1994
[Moshell et al 1995]	Moshell J., Cortes A., Clarke T., Abel K., Kilby M., Lisle C., Mapes D. and Morie J., "Research in Virtual Environments at the Institute of Simulation and Training at the University of Central Florida", Presence, No. 4, no. 2, Spring 1995, 209-217
[Nomura 1994]	Nomura J., "Virtual Reality Technology and its Applications to Industrial Use", Proceedings of Virtual Reality Software and Technology (VRST'94), August, Singapore, 125-142, 1994
[Null and Jenkins 1993]	Null C. and Jenkins J. (co-editors), A White Paper, NASA Virtual Environment Research, Applications, and Technology, October 1, 1993
[Petersen 1993]	Petersen L, "Virtual Environment Parachute Simulator (VEPS)", Annex D, in Overseas Visit Report by P. Clark, December 1993
[Pimentel amd Teixeira 1993]	Pimentel K. and Teixeira K., Virtual Reality: Through the new Looking Glass, McGraw-Hill, 1993
[Polis et al 1995]	Polis M., Gifford S. and McKeown D., "Automating the Construction of Large-Scale Virtual Worlds", IEEE Computer, July 1995,57-65
[Poston and Serra 1996]	Poston T. and Serra L., "Dextrous Virtual Work", Communications of the ACM, May '96, Vol. 39, No. 5, 37-45
[Poston and Serra 1994]	Poston T. and Serra L., "The Virtual Workbench : Dextrous VR", ACM VRST'94 - Virtual Reality Software and Technology - Conference, Singapore, G. Singh, S. Feiner. And D. Thakmann (editors), 111-122
[Poston et al 1995]	Poston T., Serra L., Lawton W. and Chua B., "Interactive Tube Finding on a Virtual Workbench", Presented at MRCAS95, Baltimore, Novemeber 5-7, 1995
[Pratt et al 1995]	Pratt D., Zyda M. and Kelleher K. "Virtual Reality: In the Mind of the Beholder", IEEE Computer, July 1995, 17-19

[Sestito 1996]	Sestito S., "Virtual Reality Technologies", Proceedings of the First International SimTecT conference (SimTecT 96), Melbourne Australia, 1996
[SmartScene 1995]	SmartScene, Technology Brief, MultiGen Inc., Email multigen!info@uunet.uu.net, 1995
[Solaiyappan et al 1996]	Solaiyappan M., Poston T., Heng P., McVeigh E., Guttman M. and Zerhouni E., "Interactive Visualization for Rapid Noninvasive Cardiac Assessment", IEEE Computer,January 1996,55-62
[Sound Spatialization 1994]	Sound Spatialization, http://bugle.cs.uiuc.edu /Projetcs/VR
[Stytz et al 1995]	Stytz M., Amburn P., Lawlis P. and Shomper K., "Virtual Environments Research in the Air Force Institute of Technology Virtual Environments, 3D Medical Imaging, and Computer Graphics Laboratory", Presence, Vol. 4, No. 4, Fall 1995, 417-430
[TTCP/SGU 1996]	Report on Achievements (1992-1996) of the UTP-2 Working Group on Virtual Reality, TTCP/SGU/96/009, 1996, (to be published)0
[Vince 1995]	Vince J., Virtual Reality Systems, Addison-Wesley Publishing, 1995
[VR Sourcebook 1996]	Virtual Reality Sourcebook, SophisTech Research, 1996 edition
[VR News 1995]	VR News, Real-Time Graphics, Vol. 4, Issue 7, pp 4, August/September, 1995
[VR Resources 1995]	VR Resources guide, AI expert, May 1995, 25-42
[Webb 1993]	Webb T., "Applications of Virtual Reality to Army Training", ERL, DSTO Report, September, 1993
[Zyda et al 1993]	Zyda M., Pratt D., Falby J., Lombardo C. and Kellenher M. "The Software Required for the Computer Generation of Virtual Environments", Presence, Vol. 2, No 2, Spring 1993, pp 130-140

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19. ABSTRACT

The aim of this report is to provide an overview of recent developments in some key virtual reality (VR) technologies and systems. Various definitions of VR will be provided. Current VR hardware (Head Mounted Displays, BOOM devices, Stereo Glasses, Convolvotron, Gloves, Tracking devices) and VR software (computer graphic issues, object representation and toolkits) will be discussed. Current innovative systems will then be presented which will include a discussion of SmartScene, PolyShop, Responsive Workbench, Virtual Workbench and the CAVE. Finally, a brief discussion of applications and areas of research will be presented.

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